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RESEARCH ON VISUAL TARGET DETECTION

PART I

DEVELOPMENT OF AN AIR-TO-GROUND DETECTION/IDENTIFICATION MODEL

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Mrs. Julie Walter and Mrs. Greta Singleton typed the manuscript and managed the preparation of the report.

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RESEARCH ON VISUAL TARGET DETECTION: PART I

DEVELOPMENT OF AN AIR-TO-GROUND DETECTION/IDENTIFICATION MODEL

Introduction

In September 1964, Human Sciences Research, Inc., was contracted by the Army Human Engineering Laboratories to conduct research on visual target detection. The objectives of the research were: (1) to develop an air-to-ground target detection/identification[1] prediction model based on the literature and available data; and (2) to set up a storage and retrieval system for the literature on visual target detection.

The final report of the research has been divided into two sections. Part II describes the storage and retrieval system. This section of the final report is concerned with development of a target detection/identification model.

Objectives and Scope

The objective of this portion of the research was to develop a model for the prediction of target detection/identification probabilities. The intended scope of the model was limited to include only unaided visual air-to-ground observation of tactical targets by trained observers. It was further limited to cover the following range of conditions: altitude--nap-of-earth to 3000 feet;

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[1]The term "detection/identification" is used throughout this report to represent a response continuum which varies from discrimination of an object of military or operational significance (detection) to precise naming and description of the object (identification). This response continuum concept is discussed later in more detail in the Preliminary Model Section of this report.

speed--hover to 350 m.p.h.; illumination--daylight (morning twilight to evening twilight); visibility--clear.[2]

Orientation

Generally speaking, research on a problem such as air-to-ground target detection/identification may follow two different approaches. One approach is a basic research orientation in which the researcher is interested in finding the precise relationships between the underlying variables and general detection performance. Research is directed toward the goal of understanding how and why each possible value of a variable affects performance. This means that the basic approach is necessarily a long-term one and is generally stimulus, rather than response, oriented. A second approach, the operational orientation, is one in which the researcher is interested in predicting performance in a specific real-world situation. The values of variables studied are constrained by actual values found in the operational environment, and the researcher is concerned with predicting as much of the specific behavior in question as possible. The response as well as the stimulus is an important consideration. The operational researcher is willing to sacrifice the greater precision and understanding of the basic approach for more immediate (and more gross) predictive power.

[2] The choice of this range of conditions was based on two considerations. The first consideration pertains to the existing capabilities of U. S. Army aircraft. For example, the speed range--hover to 350 m.p.h.--adequately brackets current speed capabilities. Second, previous field tests (e. g., U. S. Army Project LONGARM, 1959) produced findings which suggested that: (1) unaided visual observation of tactical targets under most target/ground conditions is relatively ineffective at altitudes above 2500-3000 feet; (2) under night viewing conditions, unaided visual detection is limited primarily to distinct target cues (e. g., gun flashes); and (3) under limited visibility conditions (e. g., haze, fog, or snow), most attention is directed toward aircraft and pilot safety.

For the ultimate solution of air-to-ground target detection problems, both research approaches must be used. The basic approach is necessary for an understanding of the exact relationships between performance and the variables that affect it; the operational approach is necessary to translate and apply basic findings to the operational situation. Furthermore, observations and data collected under operational field conditions often provide guidance concerning the relative importance of variables. This guidance is useful in efficiently directing research emphasis in follow-on laboratory and simulation studies.

Many of the current target detection models have followed the basic research approach. Models have been based on laboratory findings about the capabilities of the human eye (Heap, 1962; Linge, 1961; Gordon, 1963). The tendency of many theorists (e. g., Ornstein, et al., 1961; Ryll, 1962) has been to include in the models all of the variables which affect visual performance in the laboratory. The resulting models, although often mathematically precise, are of questionable validity in the operational situation. In addition, the inclusion of so many variables which have not been defined in operational terms makes actual field use of the models difficult.

To overcome these problems, the operational approach was taken in the present study. The desire for an operationally oriented model led to three criteria which such a model must meet.

1. The model must be valid; its predictions must be realistic for the operational situation.

2. The model should be simple, easy to use. Although a very complex model may predict more accurately than a simple one, its usefulness will be restricted if involved computations and estimations must be made.

3. The model should be applicable to a number of situations. It should be general enough so that it will predict performance in either information gathering missions or fire support missions which concern tactical targets.

In order to satisfy these criteria, four guidelines to model development were set up. The model should (1) be based on field data, (2) contain as few variables as possible, (3) contain variables which are defined in operational terms, and (4) be concerned with the entire detection/identification response continuum. These guidelines form the basis of the approach taken in the present study. They are discussed in detail below.

(1) Because validity is the most important consideration, the model should be based ultimately on field data. This does not mean that laboratory and analytically derived data must necessarily be left out of such a model. These types of data serve very useful functions in specifying how each of the variables should be expected to affect performance, and how the variables interact. Also, laboratory and analytical data can fill in the gaps where field data are unavailable. Basing the model on field data means, however, that controlled field research should be used to determine which variables do affect actual observer performance. The final model should consist of a weighted combination of variables with the weights determined by actual field performance data.

The use of a field data base for the model will enhance the likelihood that model predictions are realistic. Of course, it is necessary to validate the model with further tests to insure that the model is not biased by the original data and that it can be used for predictive purposes. The use of a field data base will also help satisfy the criterion of model simplicity by making it possible to relate target, environment, and aircraft variables directly to detection/identification performance. This helps eliminate the necessity for introducing intervening assumptions about the visual observation process or capabilities. Thus, the need for something like a detection lobe concept in the field model is minimized. Furthermore, it is possible to assume that the visual capabilities which had resulted in these field data would be representative of other situations.

(2) If the model is to be simple, it should contain the smallest possible number of variables necessary for "adequate" prediction.[3] There has been a tendency in current model development (Ornstein, et al., 1961; Ryll, 1962) to include initially all of the variables which affect detection/identification performance in the laboratory. Subsequent screening of these variables in field situations (Whittenburg, et al., 1959b; 1959c; 1960) has shown that many of the possible values associated with the variables taken singly and in combination simply do not occur, or occur so infrequently, in the real world that they can be neglected. In the presence of one important variable, the effects of a second variable may be completely "washed out." A simple, yet valid model should contain only those variables with demonstrable real world effects. Variables which do not add significantly to the predictive power of the model should not be included in it.

(3) To facilitate its use, the variables in the model should be defined in operational terms. If the user is required to estimate the value of some parameter, he should be able to relate the value to actual operational conditions. For example, a definition of terrain type in terms of number of slope changes per unit distance may be extremely useful for the researcher. But personnel using the model will be required to use some type of aid to be able to measure the number of slope changes in a particular terrain. A definition is needed which uses those materials and techniques that an operational user is likely to have at his disposal and which can be efficiently employed.

(4) To satisfy the criterion of generality, the model must include a range of tactically relevant responses. Previous research (Whittenburg, et al.,

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[3] A basic assumption underlying the present orientation is that the majority of air-to-ground visual observation performances can be accounted for by relatively few composite variables. Further, it is assumed that the ability to predict target detection/identification with 60-80% accuracy is operationally adequate, if not ideal. Improvement in predictive capability is a most desirable but probably a somewhat longer range goal.

1959b; 1960) indicates that aerial observers respond to targets in a manner indicating that detection/identification represents a continuum rather than discrete phenomena. This continuum is characterized by varying levels of specificity regarding the nature and identity of the target. At one extreme the response is based on the ability to merely discriminate the existence of a military object among non-military objects (detection). At the other extreme the observer can describe the object in precise detail (identification). The response level required varies according to the particular mission. For example, a reconnaissance mission may require complete and detailed description of any and all military objects encountered. On the other hand, a fire support mission may require much less response specificity; the observer may only have to decide whether or not the object is an enemy tank, without the necessity of determining whether it is a medium or heavy tank or its specific designation. If the model is to apply to more than one type of mission, it must include several response levels, each of which is tactically relevant to a particular mission.

Methodology and End Products

The methodological approach of the present study was to review the relevant literature on target detection/identification, select from the literature those variables that appeared to be most important in determining detection/identification performance, and develop a model based on the literature and field data. Because of the relative dearth of controlled field research available, however, it was only possible to develop a restricted model; i. e., a preliminary model based on a limited set of field data. The data (from Whittenburg, et al., 1959b; 1959c) were limited in the sense that the Whittenburg study was not designed for the purpose of model building. For that reason, it was not possible to evaluate the effects of certain variables. The objective in developing the preliminary model was to obtain a simple, easily calculated, data based model, which would result in realistic predictions about detection/identification performance. Since the basic data for the model were limited, however, the preliminary model is not to be considered sufficient for the range of conditions specified earlier. Further controlled field research studies are needed to meet the specified range of conditions. This topic is re-introduced later in this report. The following section of the report contains a discussion of the relevant literature on target detection/identification. The specific methodology for the development of the preliminary model is discussed in the final section of the report.

Discussion of the Literature

This section of the report is a summary of that portion of the literature on target detection/identification which was considered most relevant to model development. A list of the variables that should be important in predicting detection/identification performance is presented, the findings on each of these variables are summarized, and some suggestions for future research are given.

Relevant Literature

In the survey of the literature conducted as part of the present study, approximately 535 references were identified as being at least somewhat relevant to the general problem of visual target detection/identification. These included laboratory studies of visual capabilities, field studies of observation, simulations, analytic studies, models for predicting detection probabilities and ranges, methodological studies, reviews of the literature, and discussions of problems in current and future detection systems. Of the 535 references, 100 were selected as especially relevant for model development. These included:

1. All field studies in which some variable related to detection/identification was systematically studied.

2. All analytical studies in which a variable related to detection/identification was studied.

3. All models for predicting detection/identification performance.

4. Those laboratory studies and simulations in which the authors attempted to relate laboratory variables and findings to the field situation.

The screening eliminated from further consideration the following types of studies:

1. Field studies of (a) responses other than detection/identification; (b) equipment; (c) camouflage techniques; (d) detection under artificial illumination; and (e) field exercises in which no variables were controlled.

2. Analytical studies of atmospheric conditions, geometric representations of terrain, and studies of equipment.

3. Models for predicting responses other than detection/identification.

4. Laboratory studies of visual acuity and form perception, in which the variables were not related to the field situation.

5. Methodological studies.

6. Reviews of the literature on detection/identification.

7. Discussions of mission requirements and future system problems.

In cases where the same material was published in more than one report, only one of the reports was included.

The 100 studies selected as relevant are listed in the references section of Appendix A which also contains a numerical summary of the results of the 100 studies. The references included 26 laboratory studies, 31 field studies, 39 models and analytic studies, and 4 reports which were combinations of two of these three types of studies.

Methodology for the Selection of Important Variables

The studies selected above were used as guides in specifying variables which should be important in target detection/identification. Those variables which were studied and found to be important are discussed in the following section of the report. The resulting 24 important variables, and the number of laboratory, field and analytical studies of each are shown in Figure 1. The variables have been categorized as target, target/ground, environmental, aircraft, observer, task, and secondary variables. The latter includes variables such as apparent target size, which are composed of more than one of the single variables (e. g., apparent size includes target size and range). A complete numerical summary of all variables studied in the 100 references is given in Appendix A (in separate binding).

Although a criterion of frequency was used as a last resort to help select the variables in Figure 1, it should not be assumed that frequency of study is highly correlated with a variable's importance.[4] In many cases the variables that have been studied a large number of times are those that are relatively easy to control and vary, or those that reflect the particular interests of the investigators. The variables discussed here should be regarded as variables which may be important. As stated previously, the importance of each of the variables should be subject to future field verification.

Effects of Important Variables on Detection/Identification

Because several of the variables discussed below have been included in more than 20 studies, no attempt has been made to cover in detail all of the research on each variable. Instead, the findings on each have been summarized, along with representative reference citations whenever possible. Particular

[4]It was initially hoped that the identification of important variables would be based on such considerations as consistency of findings across studies, demonstrated significance of variables across a given range of conditions and in competition with other variables, etc. The lack of a common terminology, differences in descriptions about the research conditions, and emphasis on "one-variable" oriented studies (as contrasted with a multivariate competitive design scheme) led to the necessity of using reported frequency of the variables studied as the selection criterion.

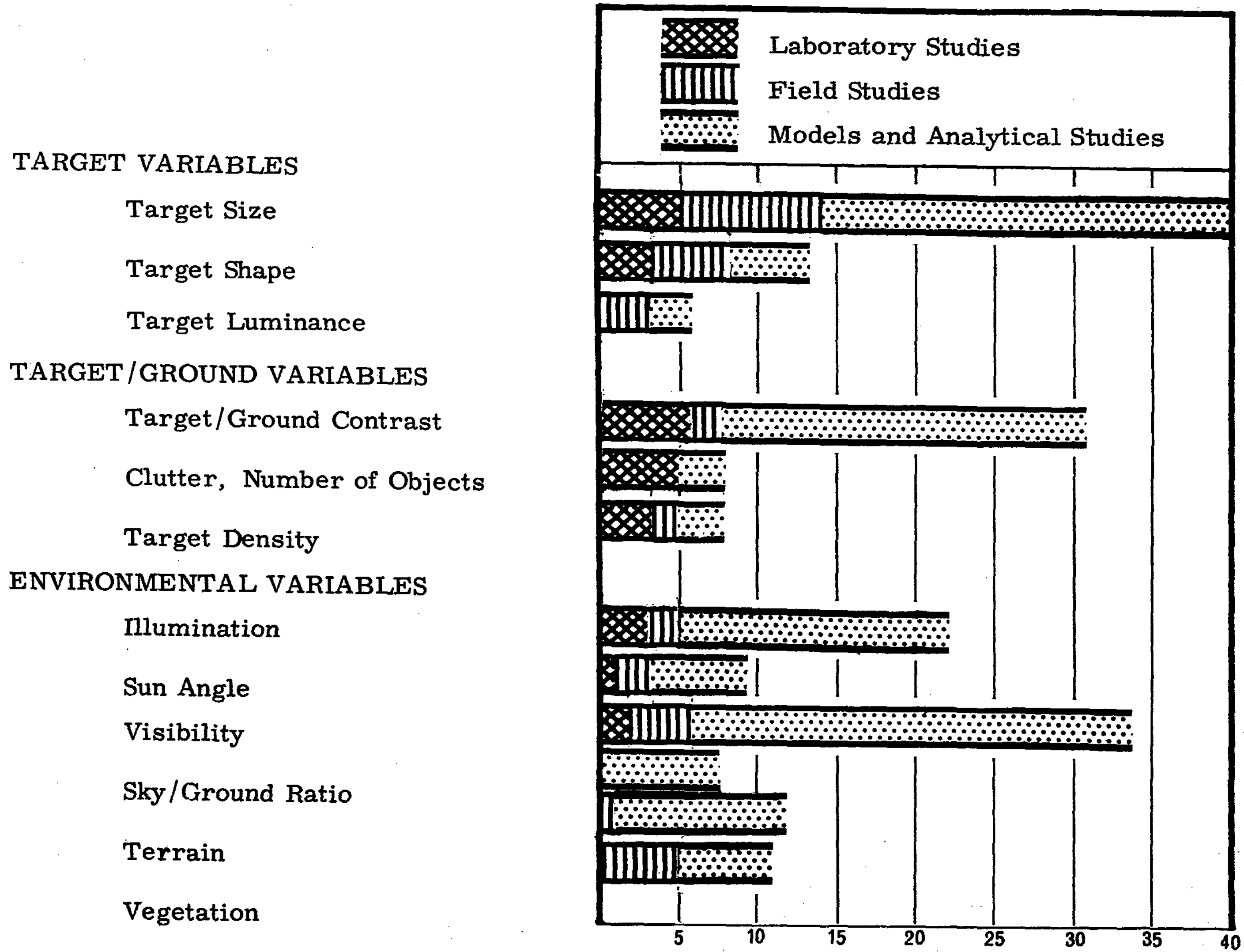
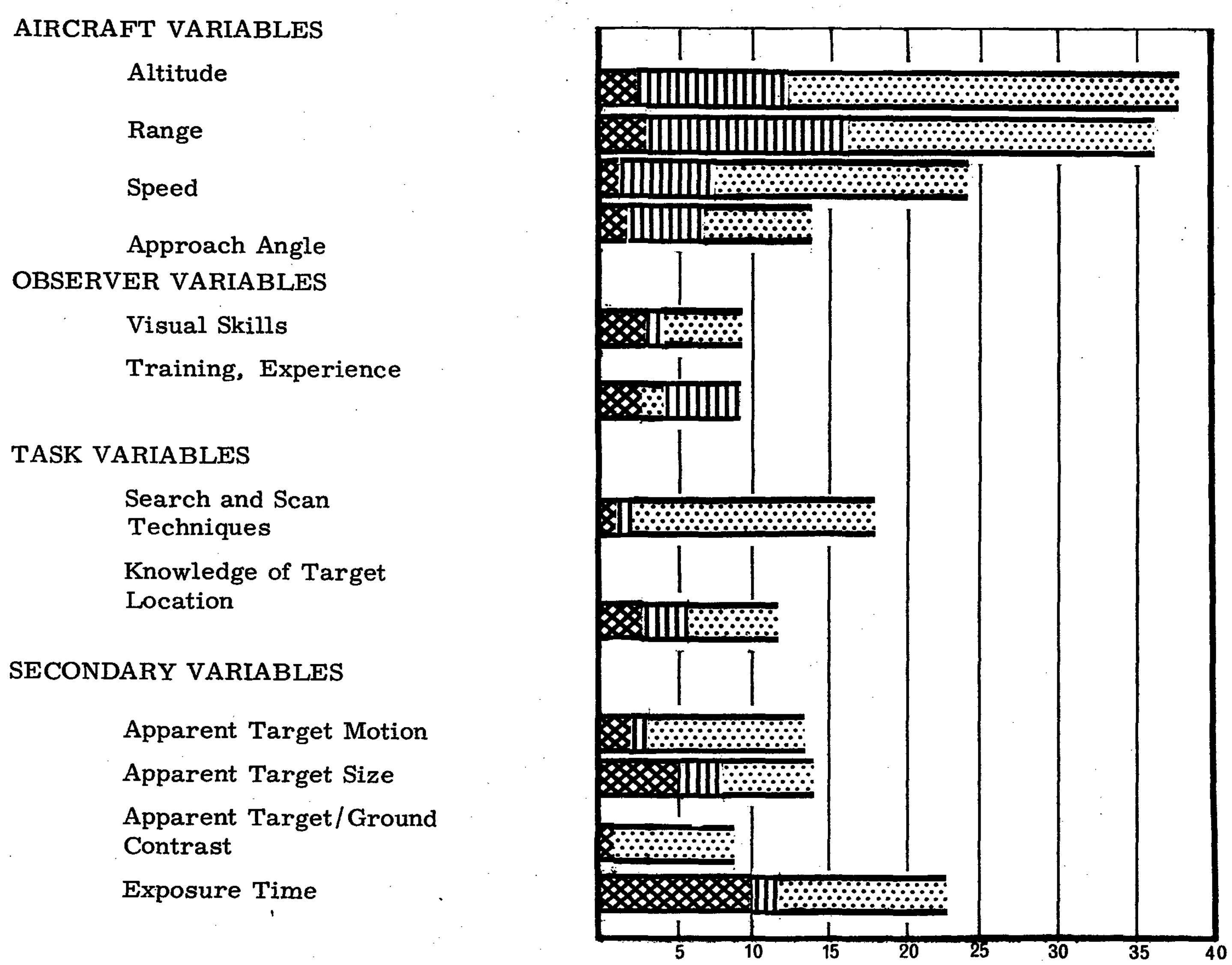


Figure 1. Number of times each variable has been studied and found to be important. The graph includes a total of 100 references--26 laboratory studies, 31 field studies, 39 models and analytical studies, and 4 combination reports.



(Figure 1 continued)

emphasis has been placed on the results of field studies. Forty-three of the 100 relevant studies are referenced in this summary.

In every study done to investigate a variable, differences in conditions, procedures, and criterion response studied have led to differences in specific findings. In this discussion, however, the general trend in the findings for a variable has been summarized. Because this is an overall summary, no attempt was made to explore the question of the differential effects of a variable on different responses. The performance responses used in the studies reviewed have included target detection, recognition, identification, and acquisition probabilities, ranges, and times. In general, where more than one response was measured, the effects of the variables were similar. The response terms reported in the summary are those of the authors. There was found to be considerable consistency among authors in the use of the terms depicting the broader categories. However, this became less true at a more detailed level.

Target Size

The effects of target size on visual detection have been investigated in a number of studies--both field and laboratory. Although size has not been systematically investigated in field studies (Dukes and McEachern, 1955; Brake, 1955), the results generally indicate that probability of detection is highest for large vehicles such as tanks and lowest for small targets such as single infantry personnel. Figure 2 shows the relationship between threshold detection range in miles and length of ships (from Richardson, 1962). In this case, detection range appears to be a positive, negatively accelerated function of target size.

Target Shape

The results of laboratory studies (National Defense Research Committee, 1946) of target shape indicate that circular targets are more detectable than rectangles of equal area, and the probability of detection decreases as

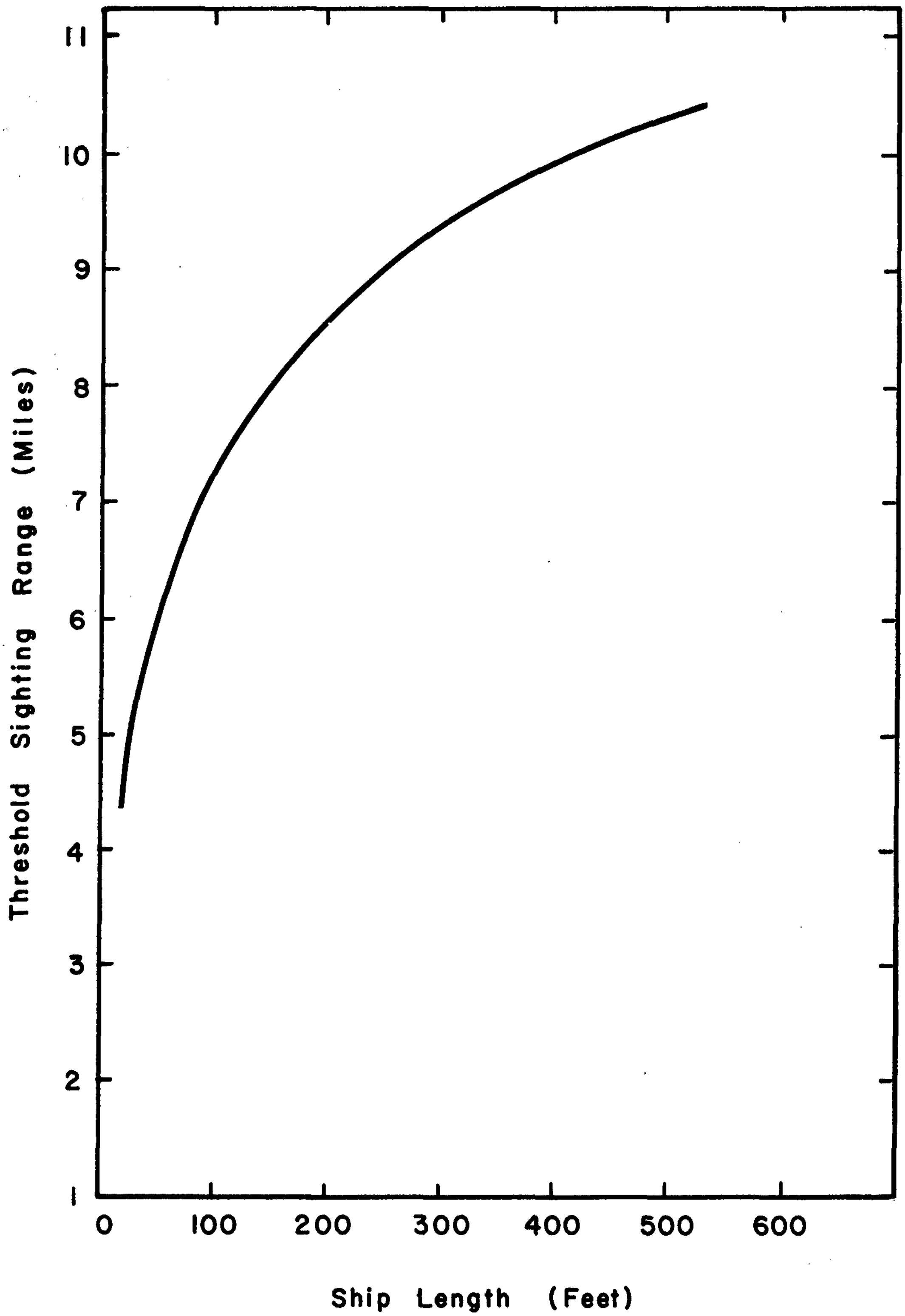


Figure 2. The relationship between target size and threshold sighting range in ship sightings (redrawn from Richardson, 1962).

the ratio of length to width increases. Most real targets tend to be rectangular in shape. These laboratory findings would suggest that targets characterized by a relatively greater length to width ratio (e. g., artillery) would be less detectable than targets such as jeeps or other targets roughly comparable in size to artillery pieces but possessing smaller length to width ratios. Target shape has not been systematically varied in the field; however, investigators have found differences in the detectability of targets of approximately equal size and contrast. These differences may be attributable to shape differences. For example, Snyder, et al., (1964) found that the probability of recognition was considerably lower for a jeep than for a small truck of the same approximate size, even when the targets were located in the same place and approached from the same direction.

Target Luminance

This variable enters into theoretical formulations on target detection/identification in combination with other variables which are used to calculate target/ground luminance contrast. As the difference between target and background luminance increases, probability of detection increases (National Defense Research Committee, 1946). Target luminance, *per se*, has not been varied in a field study.

Target/Ground Brightness Contrast

Inherent target/ground brightness contrast has usually been defined as

$$\frac{B_h - B_o}{B_h}, \text{ when } B_h \text{ is} > B_o, \text{ or}$$

$$\frac{B_o - B_h}{B_o}, \text{ when } B_o \text{ is} > B_h,$$

where B_o = luminance of the object, and B_h = background luminance. Some investigators (e. g., Boynton and Bush, 1957) have expressed the resulting fraction as a percent. The graph in Figure 3 shows the relationship found between percent correct detection and percent contrast for several observer-target distances in a laboratory study (Boynton and Bush, 1957). These findings indicate that below 30%-40%, contrast is very important in determining percent detection, but that above 40%, an increase in contrast does not have much effect. The shape of the contrast/detection function has not been verified in field studies; however, the results of one field study (Rose, 1945) are in general agreement with the laboratory findings.

Clutter

Clutter, or the number of objects in the visual field, has been found to be an important determiner of detection probability in a number of laboratory studies (Boynton and Bush, 1957, 1958; Smith, et al., 1962; Williams and Borow, 1963). As shown in Figure 4, the results of a Boynton and Bush study (1956) indicate that as clutter increases, the percent of correct detections decreases. The laboratory studies have been mainly concerned with detection of targets from displays, however. In the only field study in which clutter was investigated, Whittenburg, et al., (1959c) found no difference in detection probabilities between targets placed in relatively open areas and those placed closer to, but not concealed by, natural terrain objects. It must be noted that "clutter" has a somewhat different meaning in the field situation than in the laboratory environment. The real world is always cluttered with natural objects of some type. Difficulty in measuring clutter meaningfully within the real world context may account for the Whittenburg finding of no difference.

Target Density

Target density refers to the number of targets per unit area. Although this variable has not been systematically studied, there are indications from field work that high density, or grouped targets, may affect detection and identification differentially. Dukes and McEachern (1955) found that grouped

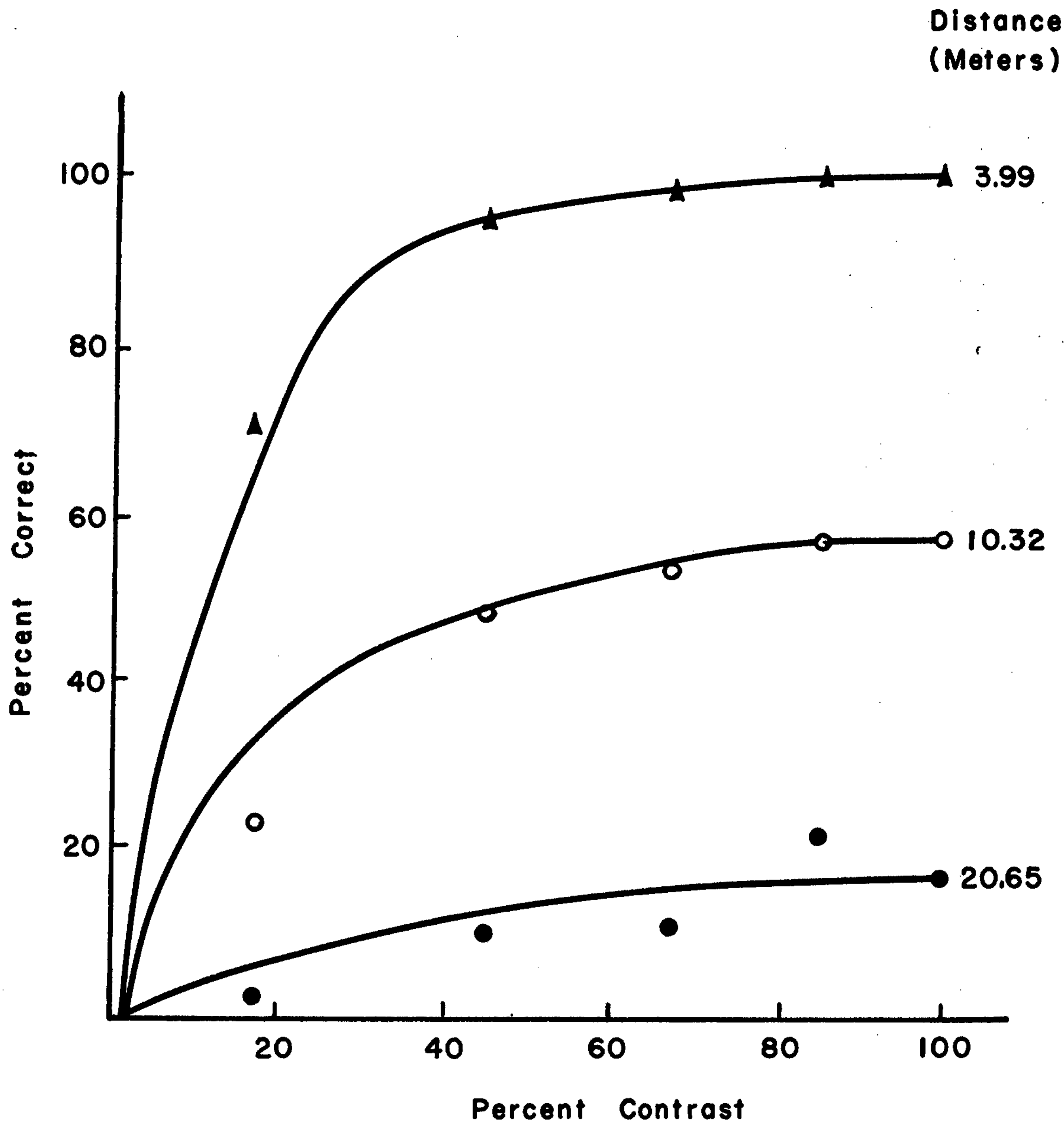


Figure 3. Percentage of correct recognition vs. contrast with distance from observer to target as the parameter (redrawn from Boynton and Bush, 1957).

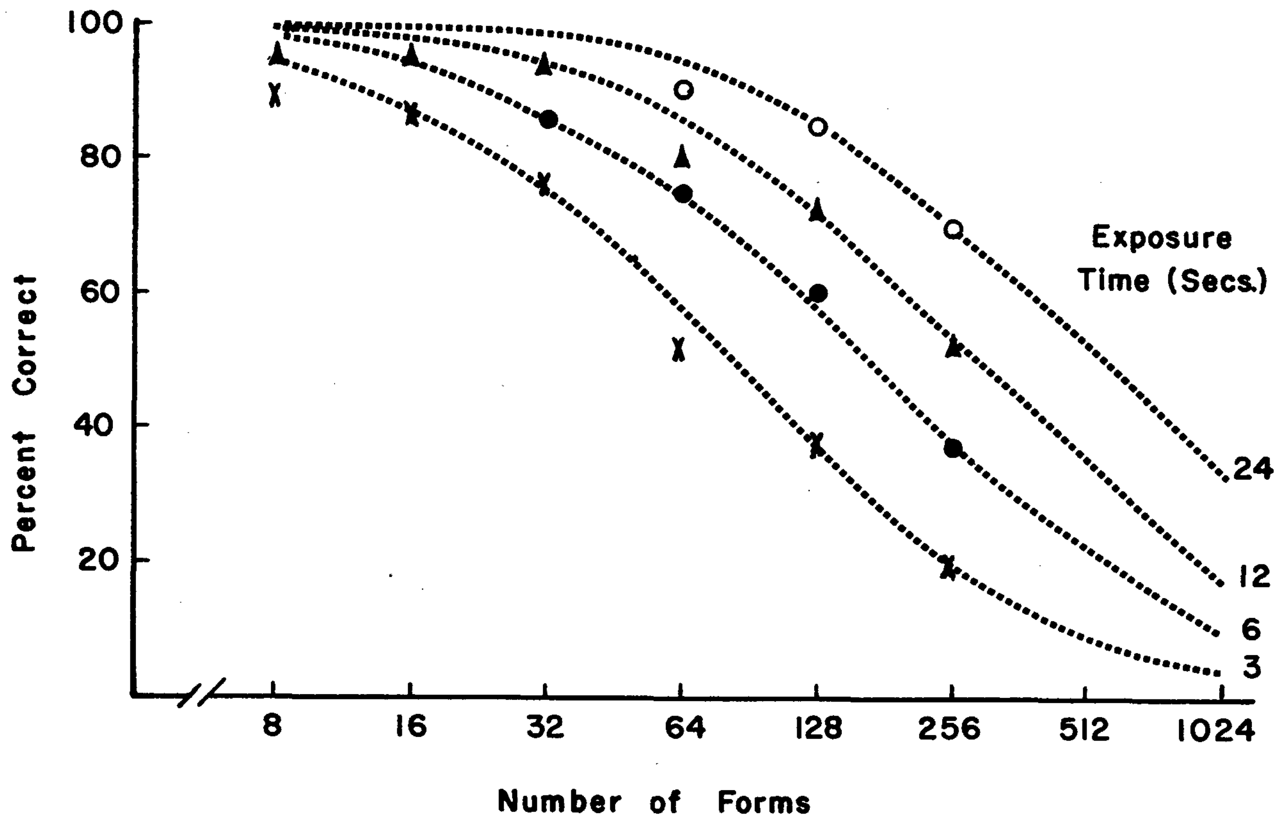


Figure 4. Percentage of correct recognition vs. number of background forms with exposure time as the parameter (from Boynton and Bush, 1957).

targets were detected more often than ungrouped ones. The authors state that, "grouping unconcealed targets thus makes the first part of the visual observer's 'to find and identify' task much simpler. Identification still remains a problem, however." In a field study of grouped targets, Whittenburg, et al., (1959b) found that in some cases the probability of identifying individual and heterogeneous targets located within a group was low. Observers tended to "lock on" one target and thus miss another target close by. Of course, when all targets in a group were the same, such as mortars, the problem of identification did not seem to exist; the only problem was that of accurately determining the number of similar targets. There was some indication from the data that targets grouped into formation patterns tended to be detected more often than those in random placements. It appears, then, that there is a trade-off involved--although grouped targets involving different types of targets may be detected more easily, there is less time available for observation and identification of each particular target in the group.

Illumination

The effects of level of illumination have been studied in both field and laboratory experiments. These include studies by Hecht, et al. (1944), Barr, et al. (1957), and the National Defense Research Committee (1946). The general findings have been that as level of illumination increases, detection performance increases. Figure 5 shows threshold detection range as a function of illumination (from Hecht, et al., 1944). It appears from this graph that in a field situation, decreases in illumination occurring after sunset are very important in determining the range at which a target can be detected. The same finding would probably apply during those periods just before sunrise.

Sun Angle

Sun angle refers to the bearing of the sun with respect to aircraft line-of-flight. The results of two field studies (Rose, 1945; Blackwell, et al., 1958) indicate that detection range is greatest when the angle between line-of-flight and sun position approaches 180°; range is lowest when line-of-flight

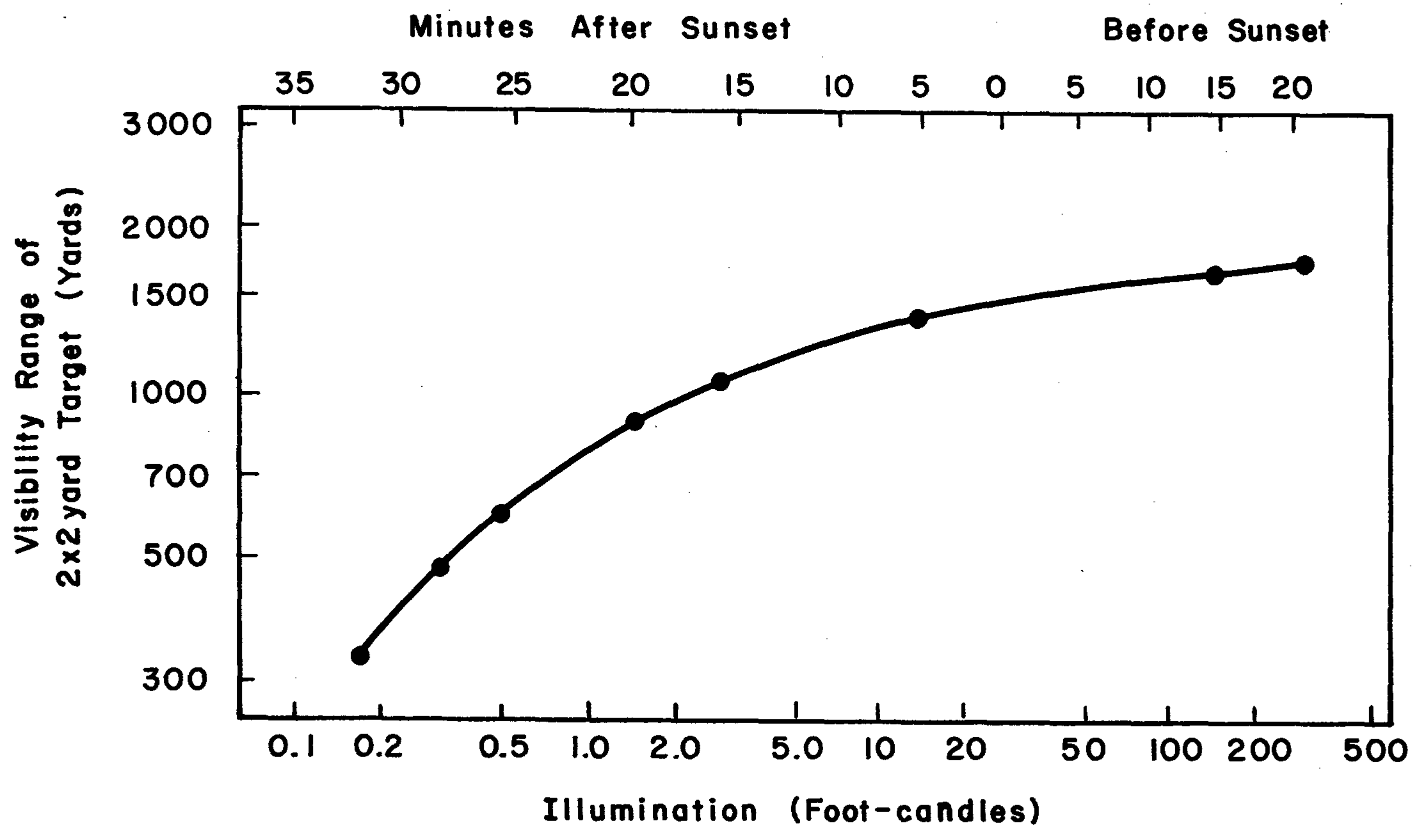


Figure 5. Visibility range as a function of illumination level (redrawn from Hecht, et al., 1944).

is toward the sun. The relationship between sun angle and relative slant range is graphed in Figure 6 (from Blackwell, et al., 1958).[5]

Visibility

Visibility has been defined in terms of visual range and in terms of contrast transmissivity of the atmosphere. The term "meteorological visibility" refers to the greatest distance toward the horizon that prominent objects such as mountains or buildings can be seen and identified by the normal unaided eye. The term "meteorological range" is defined as that distance for which the contrast transmission of the atmosphere is two percent. Middleton's book (1952) contains a summary of available information on vision through the atmosphere.

The effects of visibility and meteorological range have been investigated in a number of studies. Analytical formulations (National Defense Research Committee, 1946; Richardson, 1962) indicate that threshold detection range is a direct function of meteorological range. Typical field study results (Heap, 1963; Rose, 1945) indicate that detection range is a positive, negatively accelerated function of visibility. For example, Heap (1963) found that there was a direct relationship between detection range and visibility up to a meteorological range of about six nautical miles. Beyond six miles, however, there was only a slight tendency for detection range to increase with increasing visibility.

Sky/Ground Ratio

The ratio of sky brightness to ground brightness is an analytically derived variable. It has not been varied in laboratory or field studies.

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[5]As a passing observation, it would seem more germane with respect to performance if the definition of sun angle were based on the angle subtended by a line from a target (or center of a target area) to the observer and a line from sun position to the observer. Such a definition would tend to reflect the summed effects of both target shadows and glare on observation performance; consequently, increasing the accuracy of operational predictability.

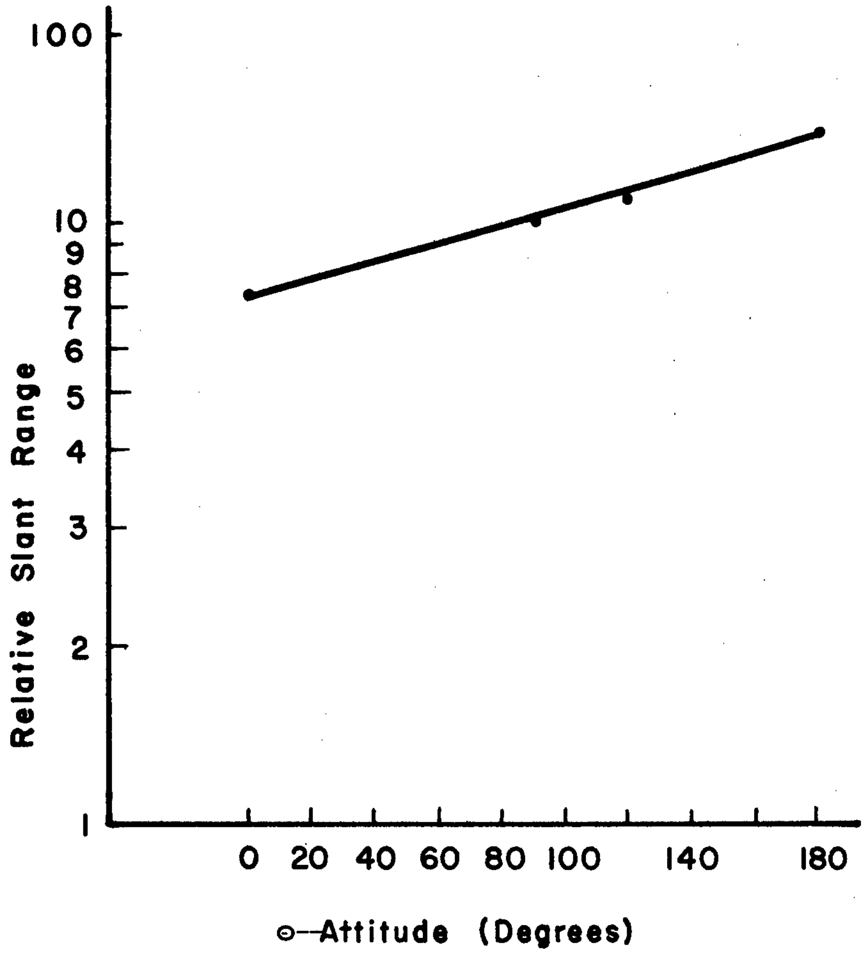

Figure 6. Log relative recognition slant range as a function of flight attitude (from Blackwell, et al., 1958). ⊖ represents the angle between the observer and the sun position.

According to Duntley (National Defense Research Committee, 1946), "The sky/ground ratio provides a means by which the law of contrast attenuation along slant paths can be adjusted for the effects of lighting conditions, ground reflectance, and the orientation of the line-of-sight with respect to the sun." Some typical sky/ground ratios are: overcast sky--fresh snow, 1; overcast sky--desert, 7; overcast sky--forest, 25. The National Defense Research Committee nomographs indicate that lower sky/ground ratios lead to higher detection ranges. This is because the lower the sky/ground ratio, the less will be the contrast-reducing effect of atmospheric scatter.

Terrain

Although the effects of terrain masking have been included in many analytic studies (e. g., Erickson, 1961; Greening and Sweeney, 1962; Linge, 1961; Ryll, 1962), the variable has not been studied in an air-to-ground field setting. Types of terrain have been defined in analytic studies in terms such as number of slope changes per unit area and average slope change. The general assumption behind analytical studies has been that rough, hilly terrain will serve to mask outlying terrain, and thus reduce the range at which a target on the ground might be seen. Figure 7 shows data from a map study by Erickson (1961) in which average percent of terrain in view is plotted as a function of altitude for four different terrain types--fairly smooth, moderately rough, rough, and very rough. Somewhat similar studies have been made by personnel from the Ballistics Analysis Laboratory (1959) and by Scovil, *et al.*, (1955).

Vegetation

The masking effects of various types of vegetation have been investigated to a limited extent in several field studies, but there have been no systematic studies of air-to-ground detection range or probability of line-of-sight as a function of vegetative masking. Drummond and Lackey (1956) measured ground-to-ground visibility range for a number of types of vegetative

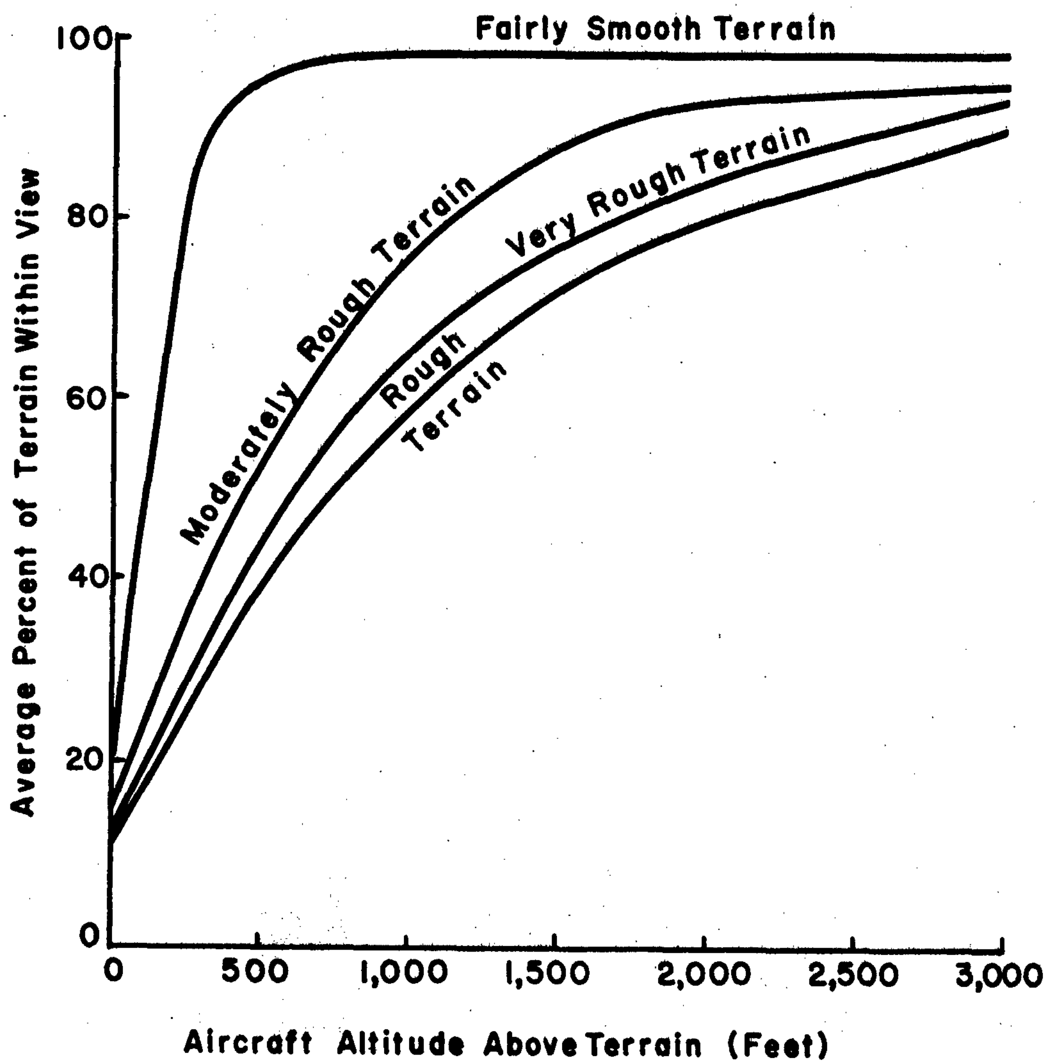

Figure 7. Average percentage of terrain seen from aircraft as a function of type of terrain and altitude (redrawn from Erickson, 1961).

growth in summer and winter and found that visibility rarely exceeded 100 yards. In a field study of air-to-ground detection, Brake (1955) found that targets in the open were detected approximately 1.8 times as often as those located in wooded areas. The data in Figure 8 (from Ballistics Analysis Laboratory, 1959) show the relative effects of vegetative masking on probability of detection. The graph is a plot of probability that a target is exposed as a function of range with foliage included and excluded.

Altitude

According to the literature, the relationship between altitude and target detection/identification is normally one in which there is assumed to be an optimal altitude. Above and below this optimum altitude, detection is reduced. In field studies which covered a range of relatively low altitudes (Heap, 1963; Gilmour, 1964; Rose, 1945), probabilities of detection and detection ranges have been found to increase as altitude increased. Studies with greater altitude ranges (Dukes and McEachern, 1955; Air Proving Ground Command, 1954) have shown, as anticipated, that as altitude is increased beyond an optimal point, detection probability falls off rapidly. A hypothetical graph of the relationship between altitude and detection range is shown in Figure 9. The reason for this relationship between altitude and detection/identification probability is that altitude affects both the amount of ground that can be seen and the apparent size of the target. As altitude increases from ground level, the effects of terrain and vegetative masking are reduced, thus increasing the probability of detection and detection range. At the same time, however, the apparent size of the target (the visual angle subtended by the target) becomes smaller, and this effect tends to decrease detection probability. Also, at higher altitudes atmospheric attenuation becomes a factor in further reducing probabilities.

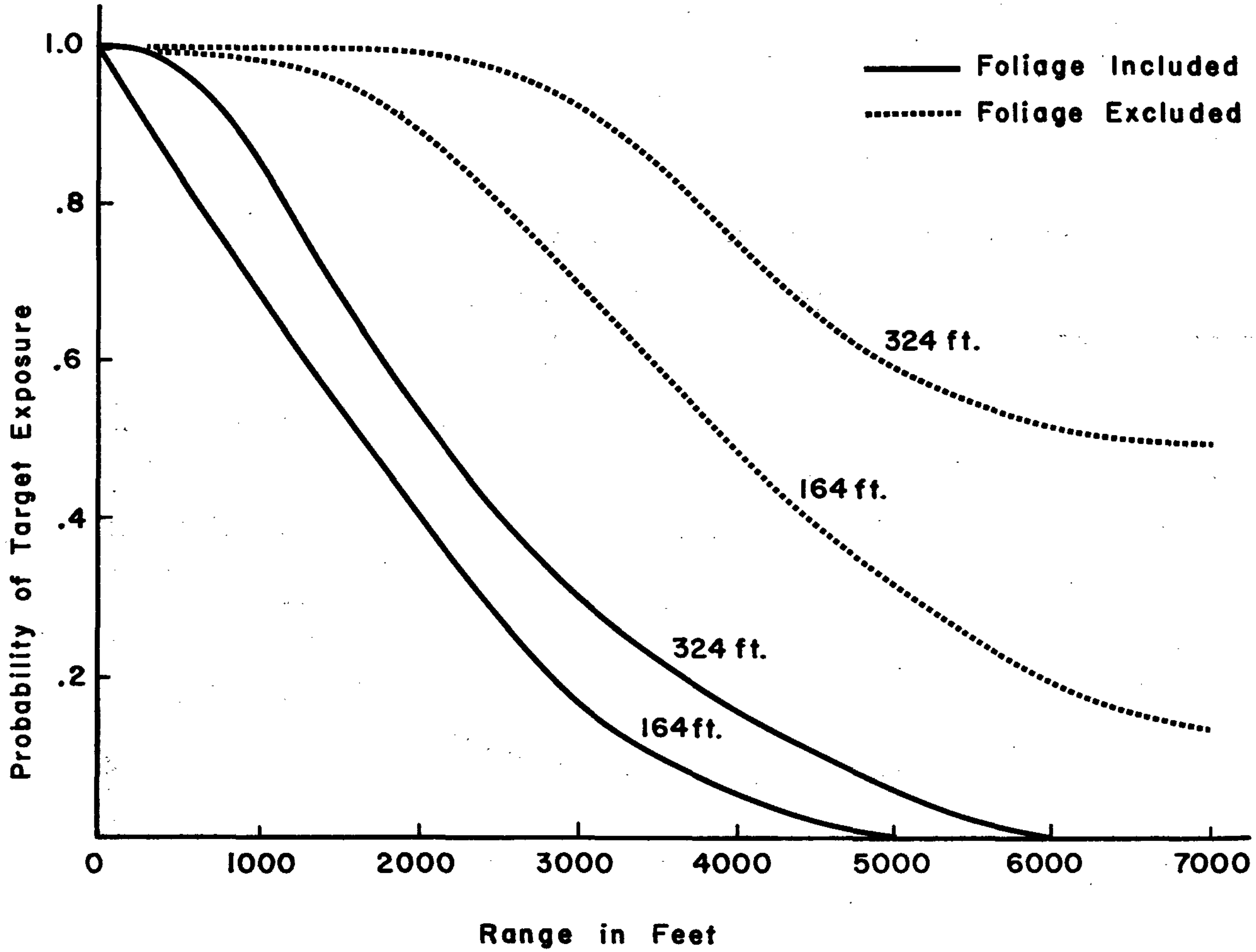

Figure 8. Average probability that a 7-foot target is exposed as a function of range and altitude with foliage included and excluded (redrawn from Ballistics Analysis Laboratory, 1959). Altitude is shown on each curve.

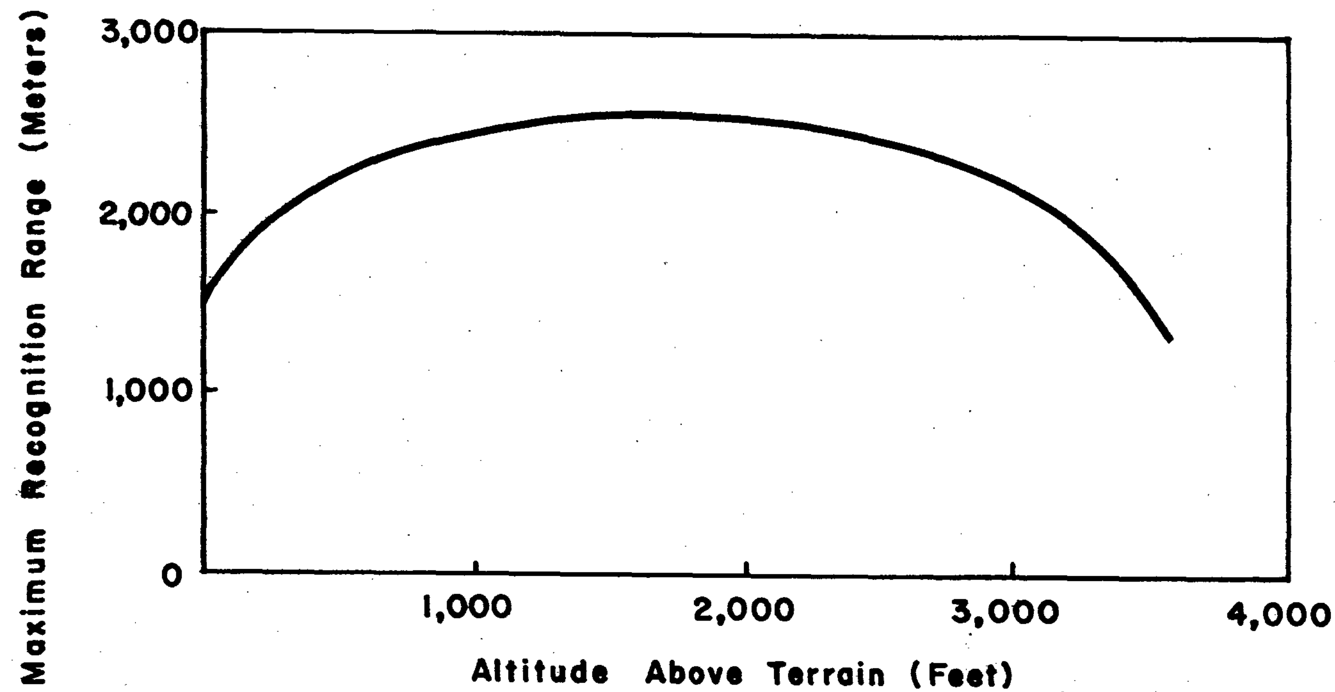

Figure 9. Effect of altitude on maximum recognition range.
Conditions assumed: target--tank; visibility--clear; terrain--rolling.

Range

Range, or distance from the observer to the target, may refer to either ground-to-ground distance or air-to-ground slant range. Range has been varied in a number of field studies (e. g., Moler, 1962; Wokoun, 1960; Rose, 1945; Whittenburg, 1959b). Typical results (from Blackwell, et al., 1958), shown in Figure 10, indicate an ogive-shaped function between recognition probability and range. As in the case of altitude, increases in the distance between the observer and the target reduce target apparent size and increase the effects of atmospheric attenuation.

Speed

The overall finding on the effects of aircraft speed on target detection/identification has been that increased speed leads to decreases in detection/identification ranges and probabilities; however, the specific results of particular field studies are not in agreement. No studies have investigated an extremely wide range of speeds. Using relatively slow speeds, Thomas (1959) found that search performance was significantly degraded as speed increased from 40 to 100 m.p.h. Heap (1963) found that both detection range and probability of detection were severely reduced when speed increased from 175-200 kts. to 300 kts. A further increase to 350-400 kts. reduced range and probability of detection only slightly. Dyer (1964) found that target acquisition distances were not significantly different at speeds of 350 and 550 kts. An increase of speed to 700 kts. did significantly reduce acquisition distances, however. Gilmour (1964) found that acquisition distance was reduced when speed increased from Mach .86 to Mach 1.2. Dyer's results are shown in Figure 11.

Approach Angle

Approach angle has been given a double meaning in the literature. It refers to the observer's view of the target at closest range and includes both the approach direction with respect to target orientation and the angle

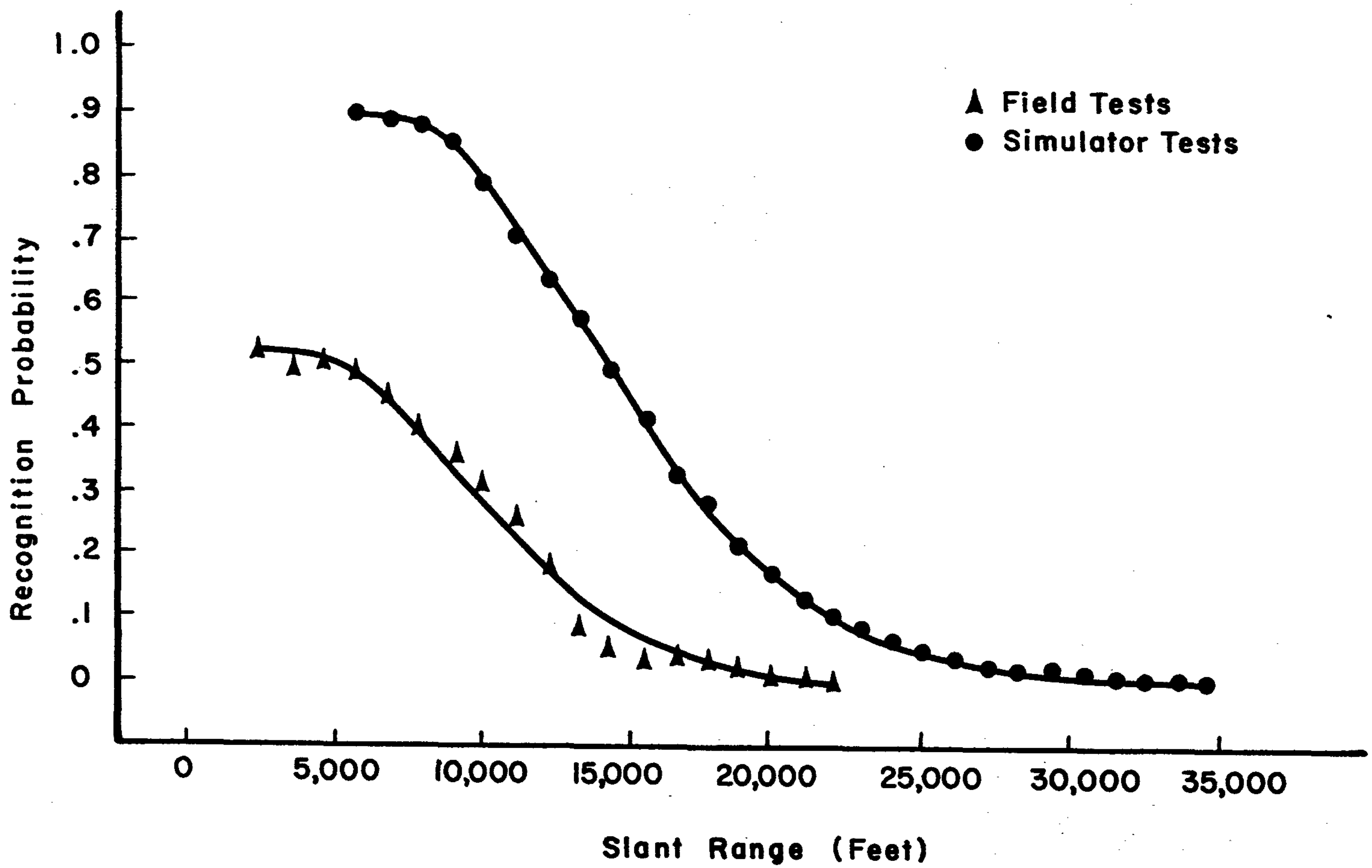

Figure 10. Recognition probability as a function of slant range--field and simulator data (from Blackwell, et al., 1958).

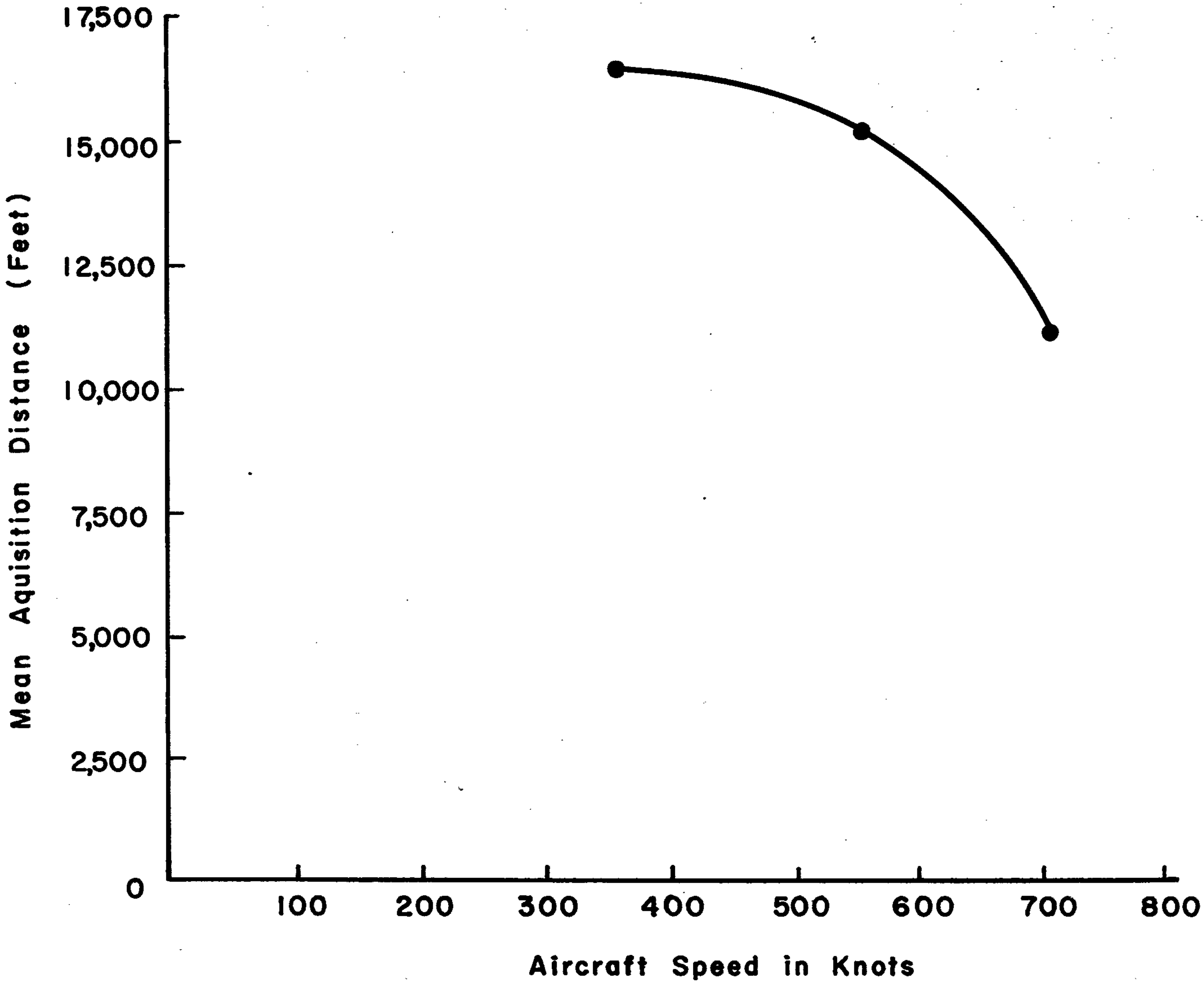

Figure 11. Effect of aircraft speed on mean target acquisition distance (from Dyer, 1964).

of view, or depression angle. With respect to direction of approach, Gilmour and Iuliano (1964) found significant differences in acquisition distances when targets were approached from two different directions. In studies of viewing angle, the usual finding (Whittenburg, et al., 1959c; Klingburg, et al., 1964) has been that detection probabilities are highest with shallow angles of view (i. e., when the observer is relatively close to the ground). Angle of view here refers to the angle subtended by a horizontal line perpendicular to the line of flight and a line from the target to the aircraft at the point of closest approach. One reason for higher performance at shallow angles may be that targets appear more familiar from this viewpoint--i. e., they are viewed from the side rather than the top. Analytical work, however, (National Defense Research Committee, 1946), also indicates that shallow angles of view should lead to higher detection probabilities, since atmospheric attenuation is least along horizontal paths and greatest at 90° angles.

Visual Skills

The relationship between the observer's visual skills and detection performance has been studied in a number of laboratory experiments. For example, Erickson (1964) found that peripheral visual acuity scores were significantly correlated with search performance in a static field. With a dynamic search task, foveal acuity became more important than peripheral acuity as display velocity increased. Goodson and Miller (1959) found that laboratory measures of dynamic visual acuity discriminated between observers' detection performances in actual flight tests at high speeds.

Training, Experience

The effects of observer experience and training on detection/identification performance have been investigated in several field studies (Gilmour, 1964; Dukes and McEachern, 1955; Whittenburg, et al., 1959c). In each case, the performance of experienced observers was superior to that of inexperienced, naive observers.

Search and Scan Techniques

This variable refers to the general scan pattern followed by an observer in searching an area. It includes the horizontal direction of scan (sideward, to the front, and so forth), the look angle downward, and the scan width. Within a controlled study setting, search and scan techniques depend on the task instructions, rather than on the observer. Natural search tendencies of the observer do have implications for the type of scan technique that can be used, however. There are indications from work on photo-interpretation (Enoch, 1958) that observers do not spend an equal amount of time on all sections of a display; rather, their natural tendency is to spend the most time on the display center.

The relative effectiveness of different techniques for search and scan has been investigated in field studies, and optimal search strategies have been determined analytically. Working with the problem of air-to-sea search for targets, Craik (1957) concluded that sweeping the eyes from left to right and right to left along a line about 3° below the horizon at about 10° per second should give the best results. Thomas, et al., (1959) tested air-to-ground detection performance with four visual search methods. The side movement method, in which the observer scanned an area 90° from the line of flight by sweeping his gaze inward toward the aircraft and outward toward the horizon, resulted in higher detection performance than did static and forward-looking methods. An example of an analytical determination of optimal search techniques is the study by Dugas (1962) in which area search and linear search patterns were compared.

Knowledge of Target Location, Size of Field Searched

The above two variables have been combined in the present discussion because neither has been studied independently. In the literature, size of field searched has been determined by the observer's predetermined knowledge of target location. Field studies on size of the field searched have generally shown that larger search radii are associated with lower detection ranges. When the observer knows where the target will be, however, detection ranges are increased. For example, Wokoun (1960) varied size of the field searched by assigning ground observers to cover a sector of the sky either 45°, 90°, 180°, or 360° in size as they searched for low flying jets. Detection and identification probabilities and distances were greater for the 45° and 90° sectors than for the 180° and 360° sectors. In a study of air-to-ground target detection, Heap (1963) varied search radius from zero to 400 yds. in 100 yd. steps. Both average range and detection probability were consistently reduced as search radius increased. Ballistics Analysis Laboratories personnel (1962) compared detection, identification and acquisition times for air-to-ground nap-of-earth search for targets located in areas with radii of 25 and 300 meters. Times for all three criterion measures were greater for the larger search area. In a study of air-to-ground target recognition at simulated speeds of 198 and 792 knots, Rusis and Calhoun (1965) found that providing the subjects with time-to-go (time before flying over the target) information resulted in an increased probability of target recognition. Figure 12 shows the results of the Rusis and Calhoun study. In the graph, "countdown" refers to time-to-go information.

Apparent Target Motion

Apparent motion, or angular velocity of the target, is a function of aircraft speed, altitude and offset distance from the target. At extremely high angular velocities, blurring occurs. A number of laboratory studies have been done to determine the effects of target angular velocity on detection (Williams and Borow, 1963; Miller and Ludvigh, 1959; Crawford, 1960). Typical results are shown in Figure 13 (redrawn from Crawford, 1960). Although detrimental effects of angular velocity have not been found in field studies of actual targets, Goodson and Miller (1959) found that visual acuity does deteriorate in the air with increased speeds in much the same manner

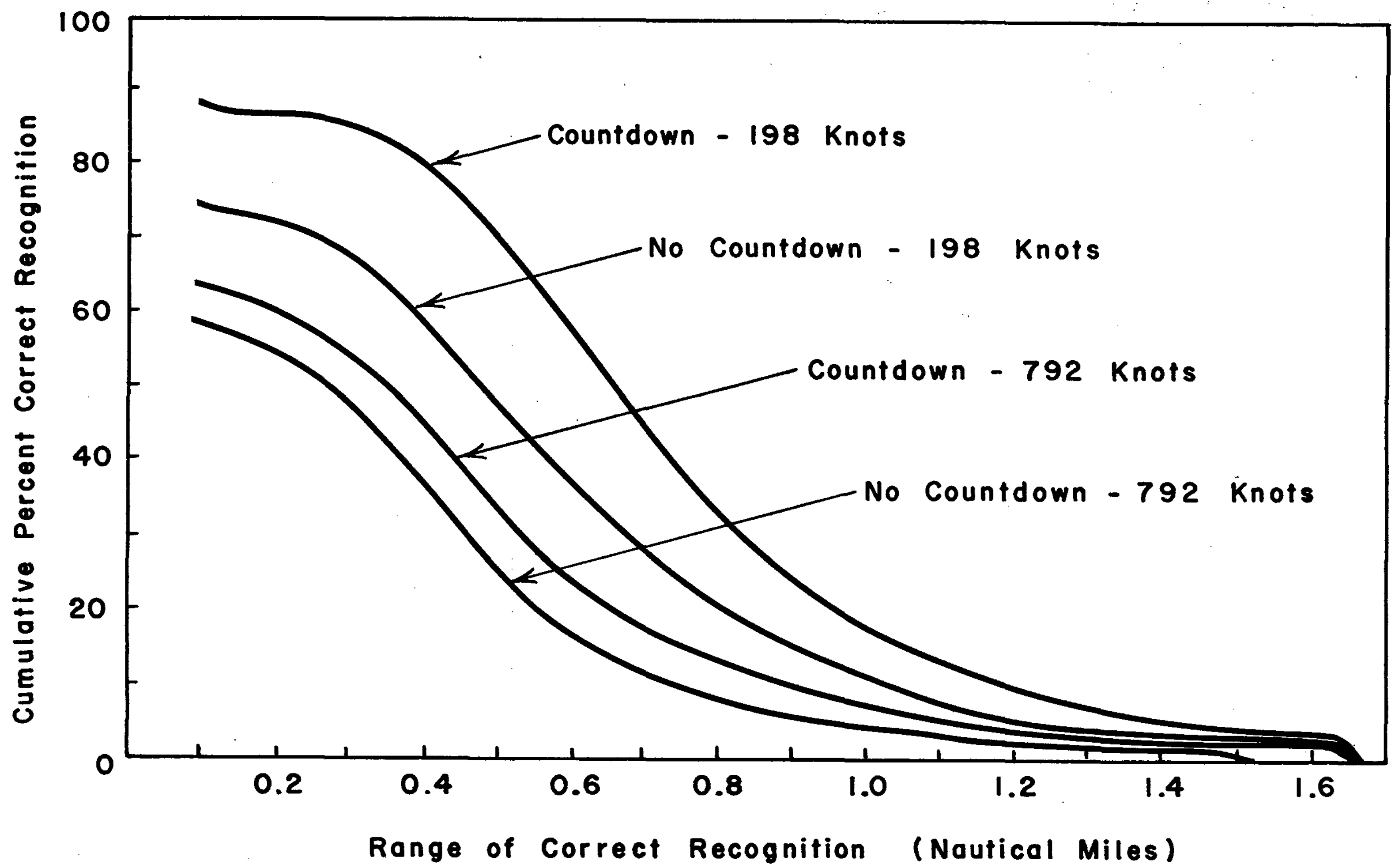

Figure 12. Cumulative percent correct recognition as a function of ground range at 198 and 792 knots for countdown and no-countdown conditions (from Rusis and Calhoun, 1965).

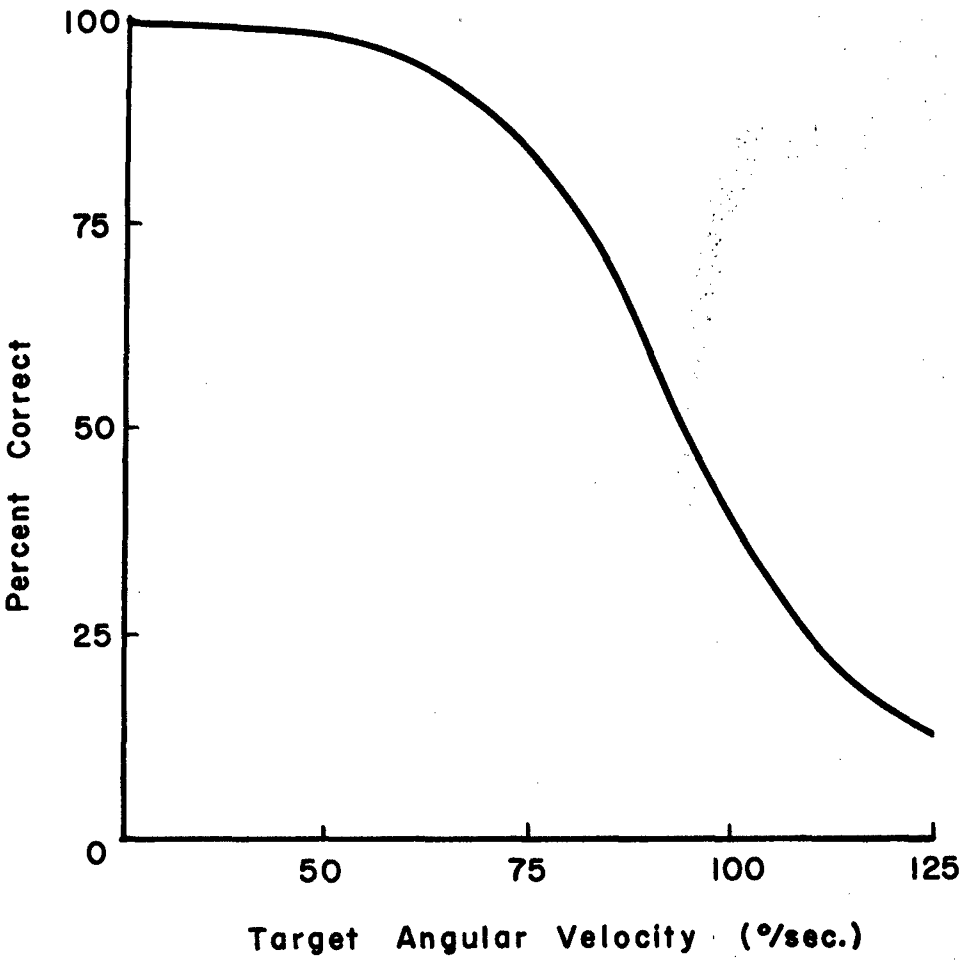

Figure 13. Percentage of targets correctly detected as a function of target angular velocity (redrawn from Crawford, 1960).

as it does in the laboratory when similar targets (Landolt C's) are used. Apparent motion may be a problem, then, in extremely low altitude, high speed flight.

Apparent Target Size

Apparent size is defined as the visual solid angle subtended by a target; it depends on actual target size and the distance between the target and the observer. Apparent size has been studied in a number of laboratory experiments (e. g., Boynton and Bush, 1957, 1958; Miller and Ludvigh, 1959; Smith, et al., 1962). The variable has also been studied in the field (Whittenburg, et al., 1959a, 1959b). Figure 14 (from Whittenburg, et al., 1959b) shows the positive relationship between apparent size and detection/identification probability that has typically been obtained. In this curve, as in similar laboratory results, it appears that with small apparent sizes, identification probability is highly related to size; with larger sizes, however, the curve levels off.

Apparent Target Contrast

Apparent contrast is defined as the ratio of the difference in target and background brightness to the total background brightness, with brightness measurements made at the location of the observer. Apparent contrast thus depends on the actual target/ground brightness contrast, atmospheric transmissivity, and the distance from the target to the observer. The effects of apparent contrast have been discussed in a number of analytical investigations (e. g., National Defense Research Committee, 1946; Ryll, 1962), but they have not been included specifically in field studies. According to the analytical studies, reductions in apparent contrast should lead to reduced detection ranges and probabilities.

Target Exposure Time

In a field situation, exposure time, or the amount of time a target is in view, depends on many factors such as aircraft speed, apparent target

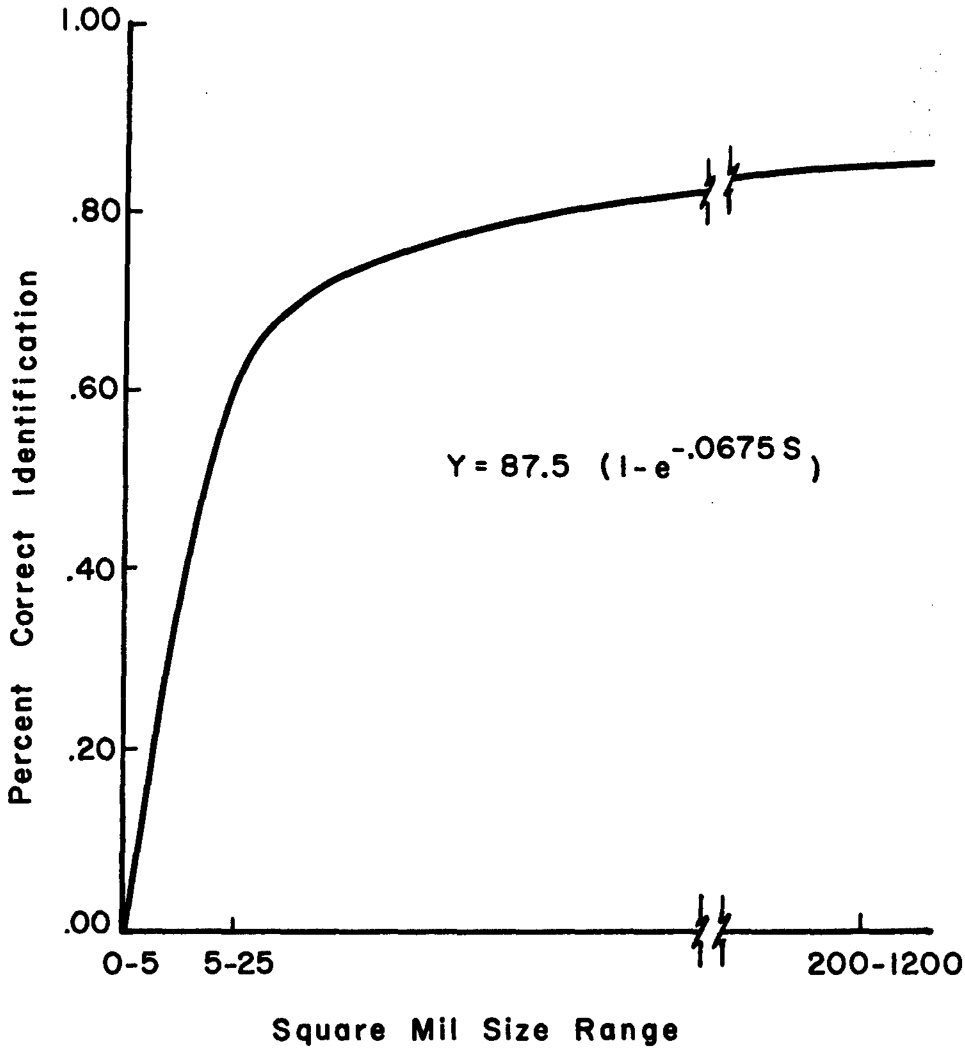

Figure 14. Percent correct target identification as a function of target square mil size (from Whittenburg, et al., 1959a).

size, and extent of masking effects. Exposure time has not yet been systematically varied in a field study; however, a number of laboratory studies have investigated its effects (e. g., Boynton and Bush, 1957, 1958; Miller, 1959; Miller and Ludvigh, 1959; Klingburg, et al., 1964; Williams and Borow, 1964). Figure 15 is a drawing (from Williams and Borow, 1964) showing the cumulative probability curve typically found in such studies. As exposure time increases, probability increases; the curve levels off at relatively long exposure times. Specific exposure times have also been used in analytic formulations as the necessary condition for further recognition or identification of targets after detection has occurred. For example, Gordon (1963) assumed that 2.7 seconds were necessary for recognition of a previously detected target.

Suggestions for Future Research

It is evident from the preceding paragraphs that a great deal of research has been done in the past few years on the problem of target detection/identification. Much of this research has been useful in specifying relationships between single variables and detection performance. However, it is difficult to apply many of the results to the operational air-to-ground target detection problem. Difficulties arise from three general problem areas: (1) definition of terms, (2) ranges of variables studied, and (3) responses studied. What is most needed now is more controlled research in which laboratory results and analytical formulations are tested in a field situation.

In field testing the effects of variables on target detection/identification performance, attention should be devoted to the three problem areas mentioned previously. First, testing should aim toward obtaining operational definitions of variables so that results may be readily applied to the operational situation. For example, to be applied to operational problems, target/ground contrast should be defined in terms of verbal or pictorial descriptions of actual target/ground combinations, rather than on a numerical percentage scale.

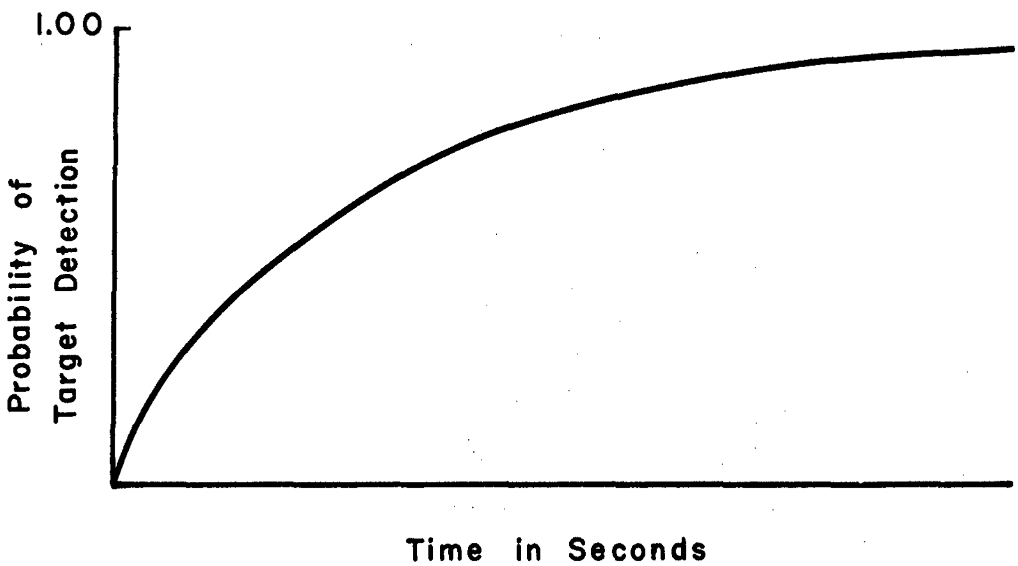

Figure 15. Target detection probability as a function of exposure time. The cumulative probability curve typically found in search situations (from Williams and Borow, 1963).

A second aspect of the field testing should be that the ranges of variables studied are restricted to those that are actually likely to be encountered in the operational situation. For example, laboratory studies have worked with brightness contrasts ranging from zero to black-on-white. In the field, however, extremely high target/ground contrast would be unlikely.

Third, in field testing, a range of several responses about the nature of the target, which are operationally meaningful, should be covered. In much of the previous research, effort has been concentrated on determining the effects of independent variables, with little attention to the actual responses being studied. Future field research should explore a range of tactically relevant responses.

The following variables are ones on which field research is especially needed: target/ground contrast, clutter, target density, sky/ground ratio, terrain, vegetation and exposure time.

Besides field research on specific variables, there is a need for more data on how variables may interact to affect performance. Although a particular variable may affect performance when it is the only one operating in a situation, its effects may become negligible in the presence of another variable. For this reason, it is necessary that multi-factor designs be used in field research.

Finally, more research effort should be directed toward testing and refining the various models which have been developed for predicting detection/identification performance.

If research proceeds along the lines suggested, it should be possible to predict a major portion of the observer's detection/identification performance. For more precise prediction and for an understanding of the true relationships between underlying variables and performance, it will be necessary to continue basic laboratory research. In the long run, an organized combination of both the simulation and the operational approaches should lead to the solution of the problem of specifying and predicting human capabilities for air-to-ground target detection/identification. This approach would combine the respective strengths of both study setting environments.

Preliminary Model

Most current models for predicting target detection/identification performance (Gordon, 1963; Ryll, 1962; Ornstein, 1961) tend to be analytically oriented and comprehensive but quite complex. The objective of the present study was to develop from the literature a relatively simple, field data based, operationally oriented model, which would result in realistic predictions of detection/identification performance under conditions of daylight and clear visibility.

It was originally desired that the model be applicable to problems of air-to-ground detection/identification of tactical targets for a wide range of aircraft altitudes and speeds. Because of the requirement that the model be based solely on existing data, however, it was not possible to include all of the factors that were considered to be important in determining detection/identification performance. Also, because of data limitations, it was not possible to include as wide a range of conditions as desired. Thus, the model developed here must be considered as a preliminary, incomplete model. The model is based on field data, however, and as such it provides a realistic approximation to the performance predictions that will be obtained when a more comprehensive model, based on additional and expanded field data, is developed.

In the following sections of the report, the development of the preliminary model and the data on which it is based are discussed. Detailed procedures for calculating model predictions are presented in Appendix B (in separate binding).

Development of the Preliminary Model

The approach taken in the present study consisted of four steps: (1) selection of a set of field data on which the model might be based; (2) selection of variables to be included in the model; (3) combination of variables into composites; and (4) determination of the best-weighted combination of composite variables. Each of these steps is discussed in detail below.

Field Data Selection

After reviewing a number of field studies, the data from a study by Whittenburg, et al., (1959a) were selected as the base for the preliminary model. This study was the only one found in the literature in which controlled field data were collected on a large number of targets which varied systematically along more than one dimension. Although the study was originally carried out with the purpose of building a proficiency field test for aerial observers, the data provided a useful base for the preliminary model.

In the Whittenburg study, air-to-ground detection/identification probabilities were obtained for 46 different tactical targets which were placed in 27 tactically realistic groups. The targets varied in size, contrast, and distance from the flight path. Each probability estimate was based on observations made by 42 inexperienced aerial observers. During flights the observers spent 100% of their time searching for targets.[6] The study was run under conditions of controlled altitude and speed. Terrain, vegetation, illumination, and visibility were the same for all tests. Table 1 outlines the conditions of the study in terms of the important variables listed in the previous discussion of the literature. From data collected in the field test,

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[6] Target observations were recorded on a tape recorder which was connected into the aircraft's intercommunication system. This permitted the observers to devote 100% of their time to searching for and reporting targets.

TABLE 1

CONDITIONS OF THE WHITTENBURG, ET AL., STUDY

VARIABLE	STUDY CONDITIONS
Target Size	Varied from small to large tactical targets, including rifles, personnel, emplaced machine guns, trucks, and tanks. Projected target areas varied from .09 sq. yd. (30 cal. MG) to 29.81 sq. yd. (M-48 Tank).
Target Shape	Varied from squarish rectangular (tanks, trucks) to elongated shapes (mortars, personnel).
Target Luminance	Varied from low (dark targets in shadow) to high (light OD colored targets in sun).
Target/Ground Brightness Contrast	Varied in the middle contrast range from a high of .79 to a low of .23.
Clutter	Target placement varied from open areas to areas surrounded by bushes, trees, etc.
Target Density	Varied from 1 to 5 targets located within a small area.
Illumination	Daylight for all tests. Tests run on both clear and cloudy days.
Sun Angle	Not recorded.
Visibility	All tests conducted in clear weather--average visibility was 14 miles.
Sky/Ground Ratio	Not recorded, but probably varied from 5 to 25.

(Table 1 continued)

VARIABLE	STUDY CONDITIONS
Terrain	Rolling.
Vegetation	Varied from heavily wooded to open.
Altitude	All tests flown at 200 feet.
Range	Nearest slant range to target varied from 230 feet to 990 feet.
Speed	All tests flown at 100 m.p.h.
Approach Angle	Not systematically varied; all targets placed in tactically realistic positions considering the terrain and simulated enemy situation.
Visual Skills	All observers had normal vision.
Training Experience	Observers were combat arms officers with no prior aerial training or experience. Ground training on target identification was given.
Search and Scan Techniques	Observers were instructed to use a side-looking pattern. The area scanned was from approximately 45° from line-of-flight to 135° from line-of-flight at depression angles from 0-90°. At the point closest to the aircraft, the scanned area was approximately 200 ft. wide.
Knowledge of Target Location	None. Observers were instructed to scan out toward horizon and in toward plane.
Target Apparent Motion	No blur effects, since speed was low and targets off-set at least 230 feet from flight path.
Target Apparent Size	At point of closest approach apparent size varied from 2070 sq. mils to 13 sq. mils.
Target Apparent Contrast	Not measured.
Target Exposure Time	Varied from 3 to 22 seconds (actual measurement.

Whittenburg, et al., found that an exact measure of target apparent size throughout the entire time it was visible (calculated from aerial photographs taken every second the target was visible) accounted for 86% of the target-target variability among observer scores.

One important aspect of the Whittenburg study which should be discussed was the response continuum measured. Observers were instructed to identify as specifically as possible the targets they saw and to report their numbers. Responses were scored on two dimensions--composition and strength. Composition refers to the level of specificity of information: four levels were designated--(1) correct name of military object, (2) correct type of military object, (3) correct class of military object, and (4) correct designation of object as a military object. Scores for strength reflected the discrepancy between the observer's estimate and the true number of targets of a given type in each target group. Composition and strength scores were scaled and combined into a single index, representing the ratio of correct to possible information given by each observer for each target. For each target, the possible score for an observer ranged from .00 (did not report the target) to 1.00 (name and number of targets correctly reported). A score between .00 and 1.00 meant that the observer had accurately reported some proportion of the total information about the target or target group in question.

In the Whittenburg, et al., study, a combined score was referred to as a detection/identification score, since it represented both ends of the response continuum. However, it was also possible to assign for each observer a "detection" score on each target (1 if the target was reported at any level of specificity; 0 if not reported); and it was possible to assign a "complete identification" score (1 if the target report was completely accurate; 0 if the report was not completely accurate).

Since the combined detection/identification scores reflected the entire response continuum, these scores--rather than the detection or complete identification scores--were used as the basic data for the preliminary model.

Because of the way performance was measured, each detection/identification score should be interpreted as the ratio of reported information to complete information. In other words, although the scores are labeled detection/identification, they really represent a proportion, of "level of complete identification" score.

Detection/identification scores for each observer were combined to yield a probability of detection/identification for each target. These combined detection/identification probabilities might be interpreted in two ways--i. e., .5 probability could mean either that half of the observers correctly identified the target, or that all of the observers made partial identification (type or class) of the target. After analyzing the distribution of individual responses for each target, it appears that, for the most part, the probability of detection/identification represents the proportion of observers who correctly identified the target. In other words, most observers either correctly identified a target or missed it entirely. Only on a few of the smallest targets did the probability represent a lower response level.

In the final section of this report, the predictions for combined detection/identification scores are compared with those for detection and complete identification scores.

<u>Variables Included in the Preliminary Model</u>

Variables to be included in the preliminary model were selected from the list of important variables discussed previously. Two general types of constraints were placed on the selection of variables: (1) information availability, and (2) operational considerations. Information availability means that to be included, a variable must be one whose effects are known, either from the literature in general or from the data of the Whittenburg study. To keep the model simple, operational considerations were used to limit the number of variables included. Variables which might be important but which could be programmed out of the operational system (via mission planning, sensor system selection, etc.) were omitted. The tactical reconnaissance system as a whole was considered as a flexible system in which conditions for target detection/identification are maximized through planning, observer training, etc. The viewpoint taken was that in the operational situation, visual observation would be used when feasible, but under unfavorable conditions, sensors other than vision would normally be used. The operational considerations constraint also included the requirement that in order that the model be useful for field prediction, the values of variables in it should be specifiable and estimable by operational personnel.

The application of these constraints resulted in the selection of eight primary input variables for the preliminary model. These were: target size, target shape, target/ground brightness contrast, clutter, terrain type, aircraft altitude, range, and aircraft speed. These eight primary input variables were used to form three composite variables--apparent target size, target distinctiveness, and exposure time. Before discussing the details of the primary and composite variables selected for the model, however, it is desirable to discuss those variables which were not included, the reasons for their omission, and model assumptions and limitations relevant to them.

Target luminance was omitted from the model as a specific input variable because it is subsumed under target/ground brightness contrast, which was included.

Target density was not included because of lack of information about its effects. Evidence from the literature suggests that grouped targets may be easier to detect than single targets; yet, because of the time sharing involved, they may be more difficult to identify. At the present time, a considerable amount of testing would be required to determine the exact relationship between target density and detection/identification performance. It should be pointed out, however, that omission of target density as a variable does not imply that the model is to be applied only to single targets.

Targets in the operational situation are almost always found in groups, and the preliminary model, based on grouped target data, will be applicable to grouped targets. The specific effects of number of targets in a group will not be included in the preliminary model, however.

Illumination. In laboratory and field studies, illumination level has been found to affect target detection thresholds, with greatest effects found at relatively low illumination levels. However, since the model developed here was restricted only to the daylight (from sunup to sundown) period and concerned with target detection/identification--rather than simple detection--illumination was not included as a variable. It is hypothesized that within the daylight range, changes in illumination level should not significantly affect visual detection/identification performance. However, as noted earlier, changes in illumination during morning and evening twilight apparently produce significant effects on target detection. Systematic investigation of performance during and around periods of twilight is needed.

Sun Angle. Sun angle has been found to affect target detection/identification. However, it was not included as a variable in the model because (1) it was not recorded in the field test and its potential contribution to performance is unknown, and also because (2) in the operational situation the flight path and the observer's direction of search may be programmed in many situations to avoid flying or searching in the direction of the sun. In essence, the operational degrees of freedom are such as to minimize, under most conditions, the effects of sun angle, *per se*, on observer performance.

Visibility. Since the model is limited to clear visibility conditions (meteorological range greater than 6 miles), visibility was not included as a variable. Under conditions of limited visibility, due to heavy haze, fog, or precipitation, sensors other than vision would probably be used in the operational situation.

Vegetation. The masking effects of various types of vegetation should be extremely important in predicting target detection/identification performance. Dense stands of vegetation may block entire areas of ground from the observer's view, and at very low altitudes single trees and bushes may intermittently mask a target from view. Although vegetation is considered to be an important variable, it was not included in the preliminary model because there are no data available on the probability of a line-of-sight from various altitudes as a function of the type of vegetation. It may very well be that vegetation produces a different effect on observation performance from that found or predicted for terrain masking. The intermittency characteristic, or "flicker" associated with viewing a target embedded among vegetation may produce quite different observer response characteristics.

Approach Angle. Although it may affect detection/identification probability, the approach angle between observer and the target is a variable which cannot be specified or estimated when predicting performance. For that reason, approach angle was omitted from the model. Targets are assumed to be located in tactically relevant positions and orientations.

Visual Skills. The visual skills of the observer were not included in the model. It is assumed that all aerial observers will have passed standard Army acuity and color vision tests.

Training, Experience. Training was omitted from the model, under the assumption that in the operational situation aerial observers will have undergone at least minimal training. Data for the preliminary model are based on observers with only ground target recognition training; if possible, the refined model will be based on the performance of observers who have received standard aerial training.

Search and Scan Techniques. The model assumes that observers will use the standard search techniques taught by the Army. Because observers in the Whittenburg study used a side-scan pattern, the preliminary model is based on such a pattern. For the refined model, however, it would be desirable to also incorporate a standard front-scan, or any other scan patterns which are currently being used by aerial observers.

Apparent Motion. During extremely low altitude, high speed flight targets in close to the aircraft may be blurred due to their high angular velocities or to air turbulence in combination with speed. Consequently, probability of detection/identification for these targets should be reduced. Blur of close-in targets is particularly a problem when using a side-scan pattern, and when front-scan cannot be used. Apparent motion was not included as a variable in the model, however, for two reasons: (1) all of the observations in the Whittenburg study were made at relatively slow speed, and no blur effects were present; and (2) the effects of apparent target motion may be reduced in the operational situation by flying low altitude, high speed missions in aircraft which permit a front scan in which targets may be picked up at a distance in front of the aircraft before they become blurred.

Apparent Contrast. Apparent contrast is a secondary variable which includes target/ground brightness contrast, distance, and atmospheric attenuation. It was not included as a variable in the model because (1) there are no field data available on its effects on detection/identification; and (2) the model is only applicable to high visibility (greater than 6 miles) conditions.

Knowledge of Target Location. Knowledge of target location, and the corresponding variable, size of the field searched, were not included in the model. It is assumed that in the operational situation, any knowledge of actual target location would go into the planning of the mission flight path; once the mission is underway, observers are assumed to be scanning all of the area covered by their scan pattern. The model further assumes, however, that observers have received a briefing on the types of targets for which they are searching, and that they know, through training in tactics, the likely positions for particular types of targets.

Omission of all of the above variables from the preliminary model limits its application and generality, and also should result in a loss of predictive precision. However, it was felt that at the present time the need is greatest for a simple, operationally useful model which will result in realistic predictions of detection/identification performance.

Combination of Primary Variables into Composites

In the operational situation, variables do not affect performance singly; they interact to affect performance. For this reason, a composite variable approach was taken in the present study. The eight primary variables were grouped into three composite variables--target apparent size, target distinctiveness, and exposure time. These composite variables may be considered as basic determinants of detection/identification performance. The primary variables contribute their effects on performance through these composite variables. Table 2 shows the primary variables which comprise each of the composite variables.[7] Apparent size is determined by target size, altitude, and range. Target distinctiveness, or the extent to which the target stands out from its background, depends on target shape, target/ground brightness contrast, and clutter. Exposure time depends on five variables--target size, terrain, altitude, range, and speed. The specific relationships between the primary variables in each of the composites are discussed below. Except for the apparent size variable, these relationships must be considered as hypotheses until they have been verified by further field research.

Target Apparent Size. Apparent size, S, is determined by the primary variables, target size, altitude, and range, with the latter two variables

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[7]The eight primary variables are the only ones included in the three composite variables. However, future expansion of the model will likely add other primary variables. For example, apparent target size is affected by the degree that the target is masked by vegetation. Also, exposure time is influenced by the extent of target offset and the depression angle; i. e., forward or side visibility.

TABLE 2

PRIMARY VARIABLES COMPRISING EACH COMPOSITE VARIABLE IN THE PRELIMINARY MODEL

	COMPOSITE VARIABLES		
PRIMARY VARIABLES	Apparent Size	Target Distinctiveness	Exposure Time
Target Size	X		X
Target Shape		X	
Target/Ground Brightness Contrast		X	
Clutter		X	
Terrain			X
Altitude	X		X
Range	X		X
Speed			X

combined as "slant range." Expressed in square mils,

$$S = A\left(\frac{3000}{D}\right)^2$$

where S = apparent target size, A = target area in square yards, and D = slant range in feet from target to observer. A mil is defined as the angle subtended by an object one unit in length at a distance of 1000 units. One mil equals 3.375 minutes of arc. In the Whittenburg, et al., study, a dimension was added to this basic definition, resulting in the definition of the square mil as the polyhedral angle subtended by an area of one square unit at a distance of 1000 units.

Target Distinctiveness. Target distinctiveness, C, is a new hypothetical variable used to bring together all of the primary variables that are related to the degree to which the target contrasts with, or stands out from, its background. This variable has been brought into the model so that all aspects of target/ground contrast--brightness, form, etc.--may be summarized in a single term. The distinctiveness variable should be thought of as a reference scale consisting of actual targets on realistic backgrounds. These target/ground combinations vary in brightness contrast, color, and form, so that the scale ranges from targets of high distinctiveness (high contrast targets located in the open) to low distinctiveness (low contrast targets located under trees, etc., or camouflaged targets). Potentially, the target distinctiveness scale could reflect a number of underlying variables--brightness contrast variables, C_b, target luminance, target/ground brightness contrast, and apparent contrast; target/ground color contrast, C_c; and variables related to target form contrast, C_f--target shape, approach angle (target orientation), target placement in patterns, and clutter.

Since such a scale is not available at the present time, distinctiveness can only be defined in general terms as a function of the three types of contrast--

brightness, color, and form; i. e.,

$$C = f\left(C_b, C_c, C_f\right)$$

It is anticipated that a distinctiveness scale will be developed when the model is validated. However, for the preliminary model, pictures of the targets used in the Whittenburg study were scaled on distinctiveness by comparing them on only brightness contrast, target shape and pattern, and clutter.

Exposure Time. For the purposes of the model developed here, effective target exposure time is defined as the total amount of time that a target is in the observer's field of view and could be detected if the observer looked at it. The drawings in Figures 16, 17, and 18 illustrate the contribution of the primary variables to effective exposure time.

As defined here, effective exposure time depends on three general sets of variables and their interrelationships. The first set of variables are those determining the size and shape of the ground area scanned by an observer. The second set includes the position of the target within the area scanned which, together with aircraft velocity, determines total possible target exposure time; the third set includes variables which limit total possible exposure time by masking the line-of-sight from observer to target.

Figure 16 shows the ground area scanned by an observer. The general shape, width, and direction of the ground area depends on the observer's scan pattern, which may be limited by the structure of the aircraft. The outward extent of the ground area depends on the threshold identification range of the target and aircraft altitude. Threshold identification range is defined as that distance at which the probability of identifying a particular target is near zero. In an earlier study, Whittenburg, et al. (1959b), found that to be identified with any probability a target must be at least 5 sq. mils in size. This 5 sq. mil finding was based on relatively small targets at close ranges, however, and when applied to large targets it results in relatively long threshold ranges.

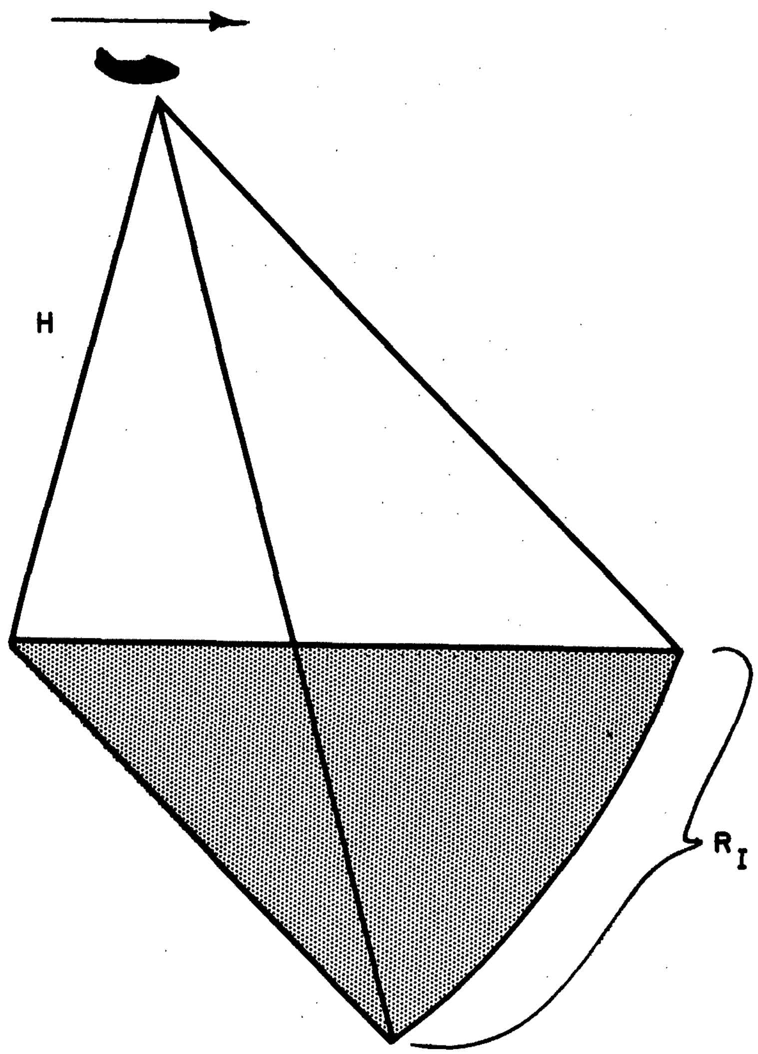


Figure 16. Ground area scanned by an observer (shaded portion). The size of the ground area scanned depends on scan pattern used, threshold range (R_I), and altitude (H). The arrow shows the direction of flight.

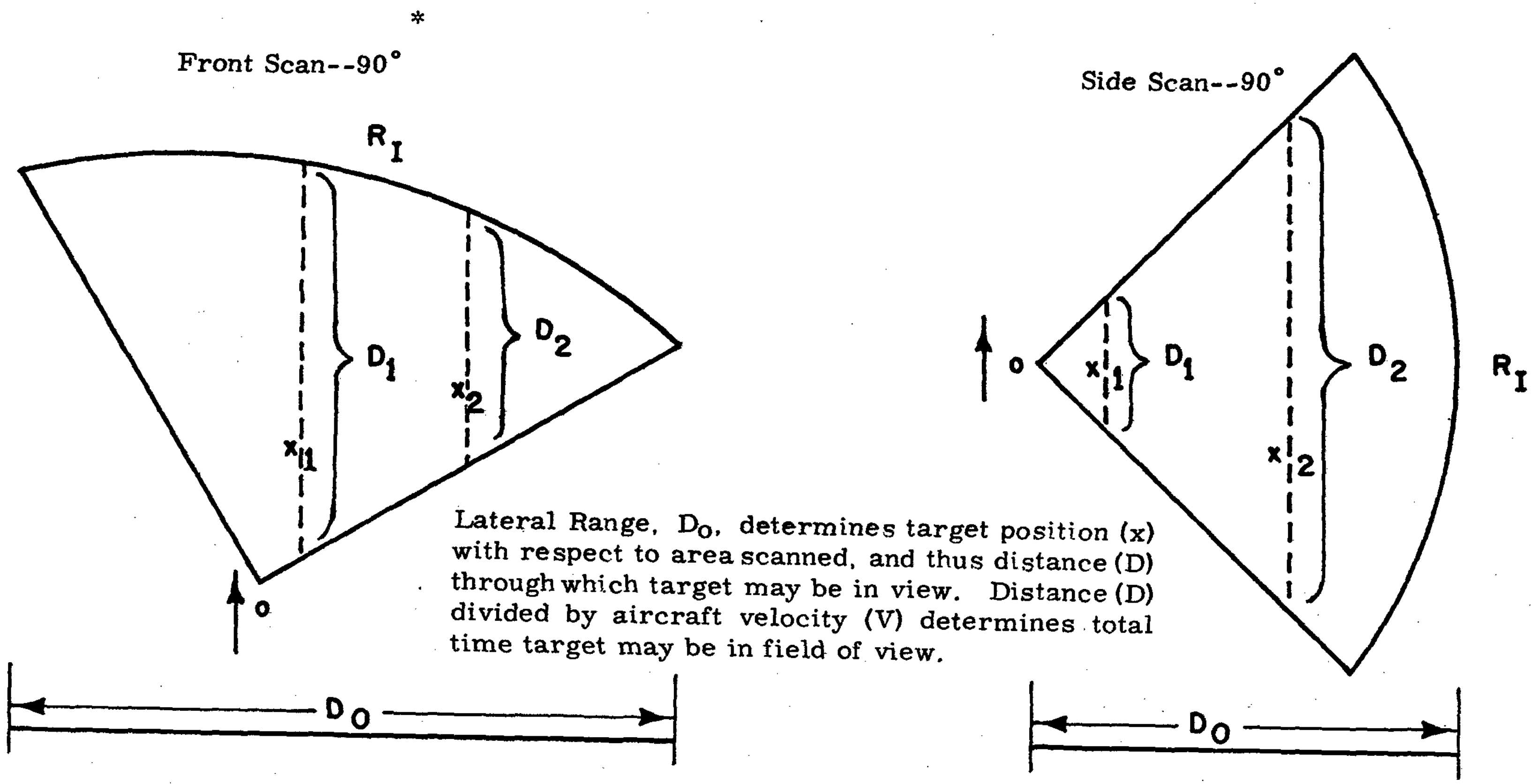
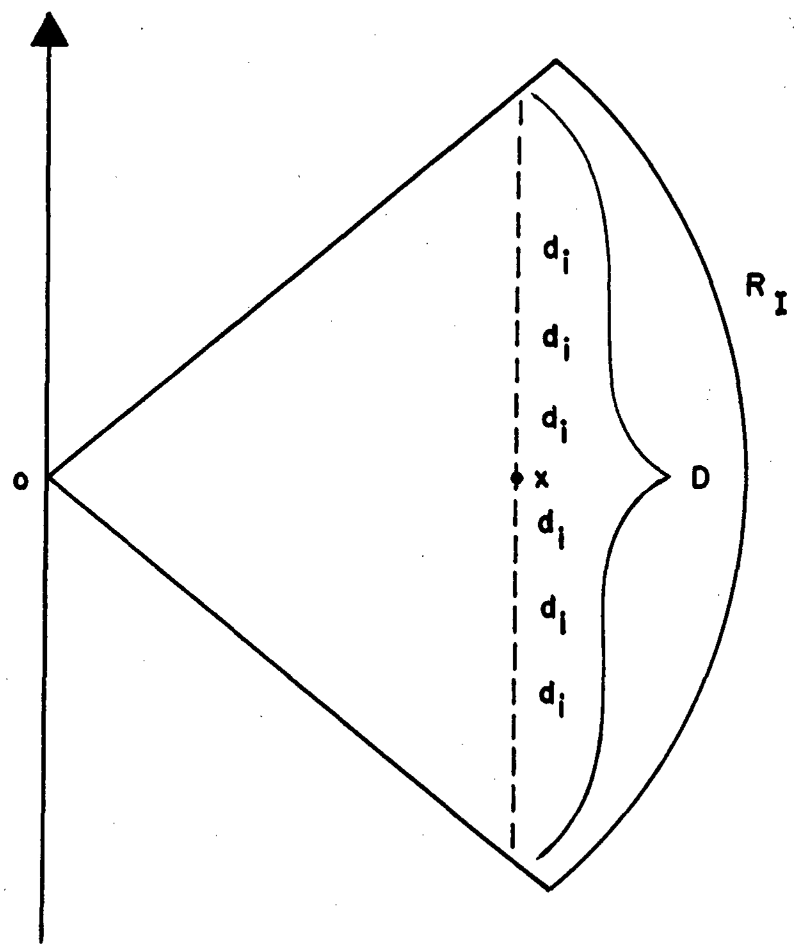


Figure 17. Two different 90° scan patterns showing how lateral range from observer to target and aircraft velocity determine total possible exposure time. The arrow shows the direction of flight in each case. The observer is located at Point 0.

*The scan area was rotated about 15° to the right of the direction of flight. The pilot's masking position (side-by-side configuration) would recommend such a shift in area scanned.

Effective exposure time depends on: (1) total possible time, and (2) probability of a line-of-sight along D.

The distance to D depends on: Lateral Range and Altitude.



Probability of seeing as far as each point along D (or each d_i) depends on type of terrain and aircraft altitude.

Figure 18. Scanned area, showing how probability of line-of-sight variables contribute to effective exposure time. The arrow shows direction of flight; the observer is at Point 0.

Although visibility, per se, was not included as a variable in the preliminary model, it was felt that even in clear weather, there would be some attenuation at long ranges. For this reason, the 5 sq. mil threshold range was modified for larger targets to include attenuation effects. Threshold identification ranges were calculated by modifying one of the National Defense Research Committee (1946) nomographs. The details of this procedure are given in Appendix B.

The second set of variables contributing to effective exposure time is shown in Figure 17. Lateral range determines the target position within the area scanned, and thus the distance through which the target may be in view. The distance the target is in view divided by aircraft velocity equals the total possible exposure time for the target.

Finally, total possible exposure time is reduced to account for the effects of terrain masking. As shown in Figure 18, the probability of a line-of-sight along the target path depends on the type of terrain, aircraft altitude, and the distance between observer and target at each point along the path. For example, when flying at extremely low altitude over rough terrain, the average probability of seeing along the target path will be less than 1.0, and hence the target will not be in view all of the possible time. In the preliminary model, average probability of a line-of-sight to the target was obtained from a set of graphs from a study by Erickson (1961). This probability estimate was then used to reduce total possible time to effective exposure time. Copies of the Erickson graphs are shown in Appendix B.

To summarize the preceding paragraphs, effective exposure time depends on (1) the shape and extent of the ground area scanned (determined by observer scan pattern, aircraft altitude, and threshold range, which depends on target size); (2) total possible exposure time (determined by lateral range and aircraft velocity); and (3) probability of a line-of-sight along the target path (determined by lateral range, aircraft altitude, and type of terrain).

Determination of the Best-Weighted Set of Composite Variables

To obtain the best-weighted set of composite variables, measures on apparent size, distinctiveness, and exposure time were obtained for each of the 46 targets used in the Whittenburg study. A trial-and-error graphic solution was used to find the combination of the three composite variables which would predict most accurately the actual detection/identification probability obtained for each target in the study. A graphic solution was used for the combination of variables in the preliminary model because of time limitations; however, if more data are obtained during model validation, a statistical method such as multiple correlation will be used to select the best-weighted composite. A summary of the measurements and calculations made on the Whittenburg data is presented below. Appendix B includes details of the procedure and the actual values obtained for each target.

Target Apparent Size. Since the Whittenburg study included targets varying in actual size and distance from the observer, the apparent size of each target at each point along its path could be determined using the formula,

$$S = A \left(\frac{3000}{D}\right)^2$$

where S = apparent size in sq. mils, A = target area in sq. yards, and D = slant range in feet.

Target Distinctiveness. Color photographs taken from the actual flight path at the point of closest approach were available for each target in the Whittenburg study. The targets in these photographs were assigned scale values on distinctiveness. As mentioned previously, for the refined model a reference scale of target distinctiveness will be developed. This scale will include pictures and verbal descriptions of actual targets on realistic backgrounds, ranging from high distinctiveness (high contrast targets in the open) to low distinctiveness (low contrast targets in cluttered areas).

Once the distinctiveness reference scale has been developed, any new target may be assigned a distinctiveness value by comparing the new or expected target with the scale. A reference scale was not available for the preliminary model, however, so pictures of the targets were assigned values on a 12-point distinctiveness scale. In assigning the values, attention was paid to the brightness and color contrast of the target against its background, target placement in patterns, and background clutter. Targets from the Whittenburg study which seemed to stand out most from their backgrounds were assigned values of 12. Those with less distinctiveness were assigned lower values. As an example, a high-contrast tank located in the open along the edge of a road received a distinctiveness value of 12; a tank covered with a camouflage net and located off of the road against a background of large bushes received a value of 3. Overall, the target distinctiveness values ranged from 1 to 12.

Exposure Time. Exposure time for each target was calculated by determining (1) the size of the ground area scanned by observers in the Whittenburg study, and (2) the position of the target relative to the area scanned. Observers in the Whittenburg study were instructed to use a standard side-looking scan pattern, scanning out toward the horizon and in toward the aircraft. Because of the structure of the aircraft, the area scanned was from approximately 45° from the line of flight to 135° from the line of flight. At the point closest to the aircraft, the scanned area was approximately 200 ft. wide. Figure 19 shows the ground area scanned from the plane. The farthest extent of the area scanned, the threshold identification range, was estimated by determining that range at which the target was less than 5 sq. mils in size. This range was chosen because Whittenburg, et al., (1959b) found that targets of less than 5 sq. mils could not be identified, even when the observer knew the exact target location. The threshold identification range was obtained by modifying one of the National Defense Research Committee (1946) nomographs. Details of this procedure are given in Appendix B. In modifying the nomograph

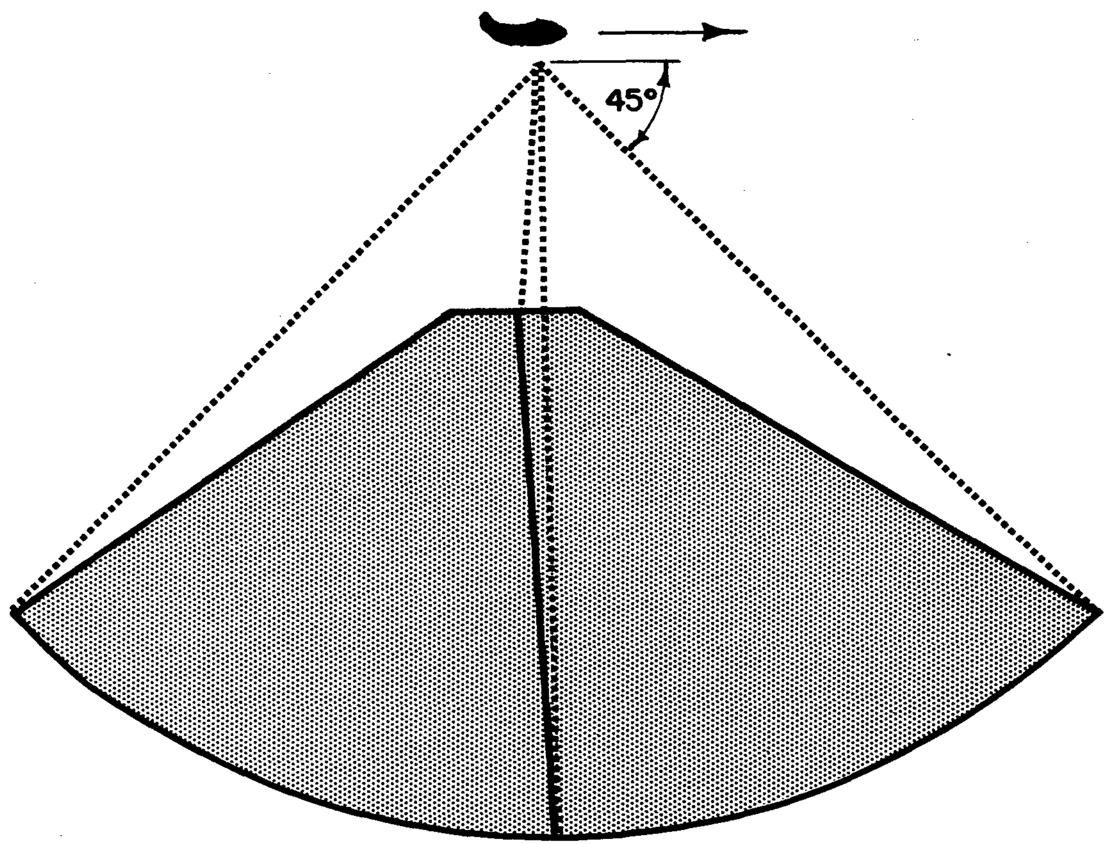


Figure 19. Ground area scanned in the Whittenburg study.

to determine a threshold detection/identification range curve for "average operational conditions" it was necessary to include estimates of the Whittenburg study values for target size, target/ground brightness contrast (.5), illumination level (100 ft. lamberts), meteorological range (14 miles), and sky/ground ratio (5--clear/forest). The resulting curve is shown in Appendix B, along with the details of its construction.

Total possible exposure time for each target was then obtained by determining the ground distance through which the target was in view and dividing this distance by aircraft velocity. To obtain effective exposure time, each total time value was degraded by the average probability that there was a line-of-sight along the target path. Probabilities of line-of-sight were obtained from a map study by Erickson (1961) in which probability of a line-of-sight to a given range was determined as a function of altitude and terrain type. The appropriate study parameters--200 ft. altitude and rolling terrain--were used to find probabilities of line-of-sight for the targets in the Whittenburg study.

Combination of Composite Variables

Combination of the three composite variables into the preliminary model was done using a trial-and-error graphic procedure. Of the many possible ways the variables could be combined, five were selected and tested. For each combination tested, composite values were plotted against actual detection/identification probabilities. Table 3 shows the combinations tested and the correlation ratio (η) of each combination with probability of detection/identification. That combination of the composite variables which yielded the highest correlation was $(\sqrt{S})$ (C) (T_e), or the square root of target average apparent size times target distinctiveness value times effective exposure time, where effective time score equals 1 when total time is greater than 5 seconds. Thus, the most predictive combination of variables included time only as a degrading factor. All exposure times greater than 5 seconds were effectively equal to 1; when exposure time was less than 5 seconds, the effective time was less than 1.

TABLE 3

CORRELATION BETWEEN COMBINATIONS OF COMPOSITE VARIABLES AND DETECTION/IDENTIFICATION PRCBABILITIES

Combination	Eta (η)
$S_e = ST$, where S_e = effective target size exposed S = maximum target apparent size T = effective exposure time (total time adjusted for probability of line-of-sight)	.66
$S_e = \bar{S}T$, where $\bar{S}$ = average apparent size T = effective exposure time (total time adjusted for probability of line-of-sight)	.69
$S_e = \bar{S}CT$, where $\bar{S}$ = average apparent size C = target distinctiveness value T = effective exposure time (total time adjusted for probability line-of-sight)	.75
$S_e = \sqrt{\bar{S}}\,C\,(T/5)$, where $\sqrt{\bar{S}}$ = the square root of average apparent size C = target distinctiveness value $T/5$ = effective exposure time (total time divided by 5 and adjusted for probability of line-of-sight)	.85
$S_e = \sqrt{\bar{S}}\,CT_e$, where $\sqrt{\bar{S}}$ = the square root of average apparent size C = target distinctiveness value T_e = effective exposure time = T_s adjusted for probability of line-of-sight: when Total time/5 1, $T_s \geq 1$ when Total time/5 1, $T_s < \sqrt{T/5}$	.87

The graph in Figure 20 shows the best fitting line for this final combination of variables plotted against probability of detection/identification for the Whittenburg, et al., data. The slope of the line is given by the formula:

$$P_{TDI} = 1 - e^{-.0167S_e}$$

where P_{TDI} = probability of target detection/identification, and $S_e = \sqrt{S}\,CT_e$.

As discussed previously, the detection/identification response on which the curve is based represents a level of response detail. With such a base, the predicted probabilities could be interpreted in more than one way. To show how the detection/identification probability curve compares with probabilities of simple detection and of complete identification, Figure 21 was constructed. The curve labeled "detection" represents the proportion of observers who responded at the detection level (designation of the object as a military target) or higher. The curve labeled "identification" represents the proportion of observers who correctly named the target. As expected, all three curves follow the same general shape, with the detection/identification curve lying between the other two. Actual probabilities of detection, identification, and detection/identification of each target are presented in Appendix B.

Model Predictions and Limitations

Using the relationships developed above and the rules for the calculation of model values in Appendix B, predictions of target detection/identification probabilities were calculated for several examples. Figure 22 shows predicted probabilities for detection/identification of a high contrast tank (assumed C = 12) as a function of terrain type and slant range. For this example, aircraft altitude was fixed at 100 ft., and speed at 100 m.p.h. Figure 23 shows an example of the predicted effects of altitude on detection/identification of a high contrast tank (C = 12). Rough terrain and a speed of 100 m.p.h. are assumed in this example. Figure 24 presents a comparison of the effects of three values of target distinctiveness (C = 2, 6, and 12) on detection/identification of a tank on rolling terrain at 100 ft. altitude and speed of 100 m.p.h.

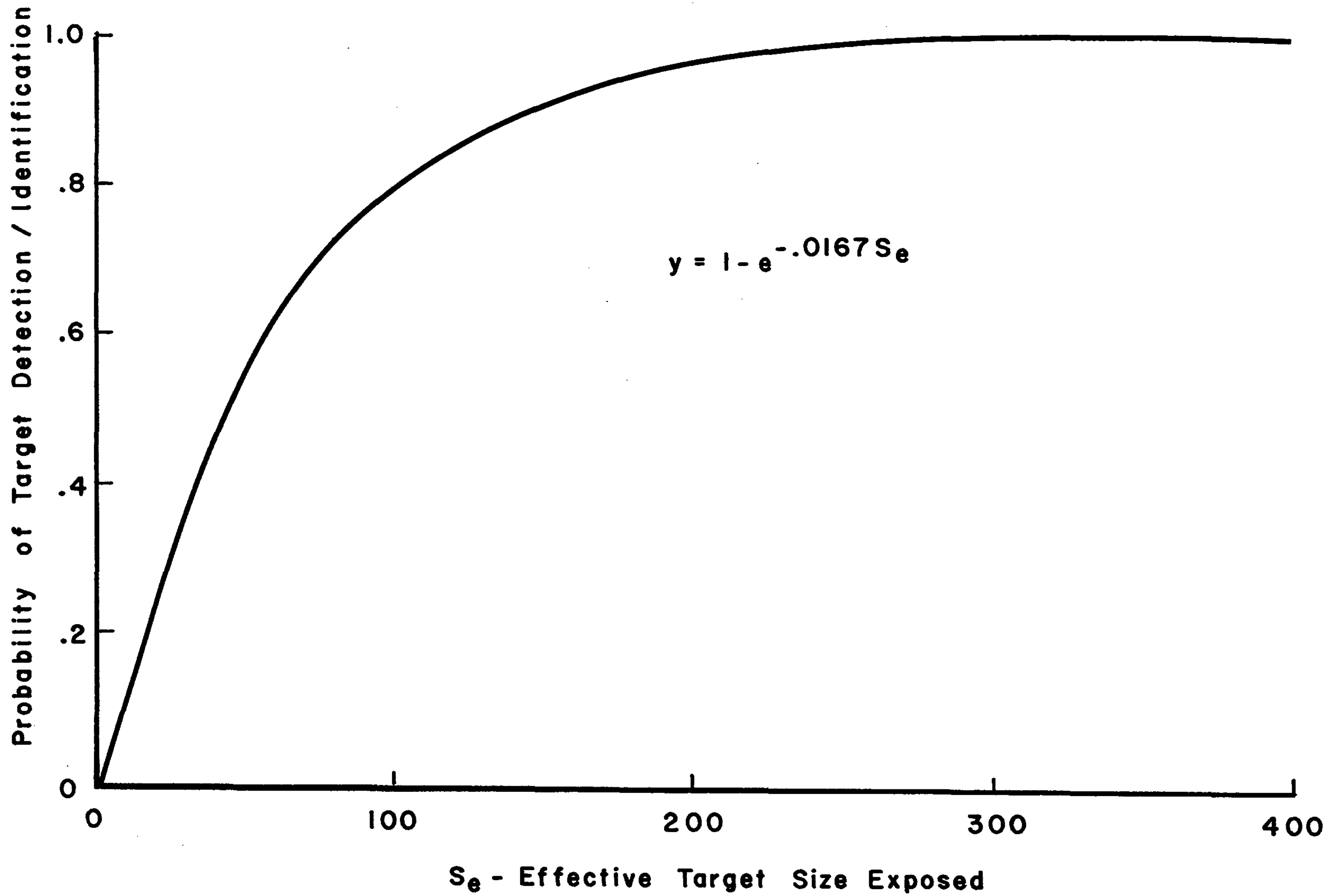


Figure 20. Probability of target detection/identification as a function of effective target size exposed. This figure is based on data from Whittenburg, et al. (1959a).

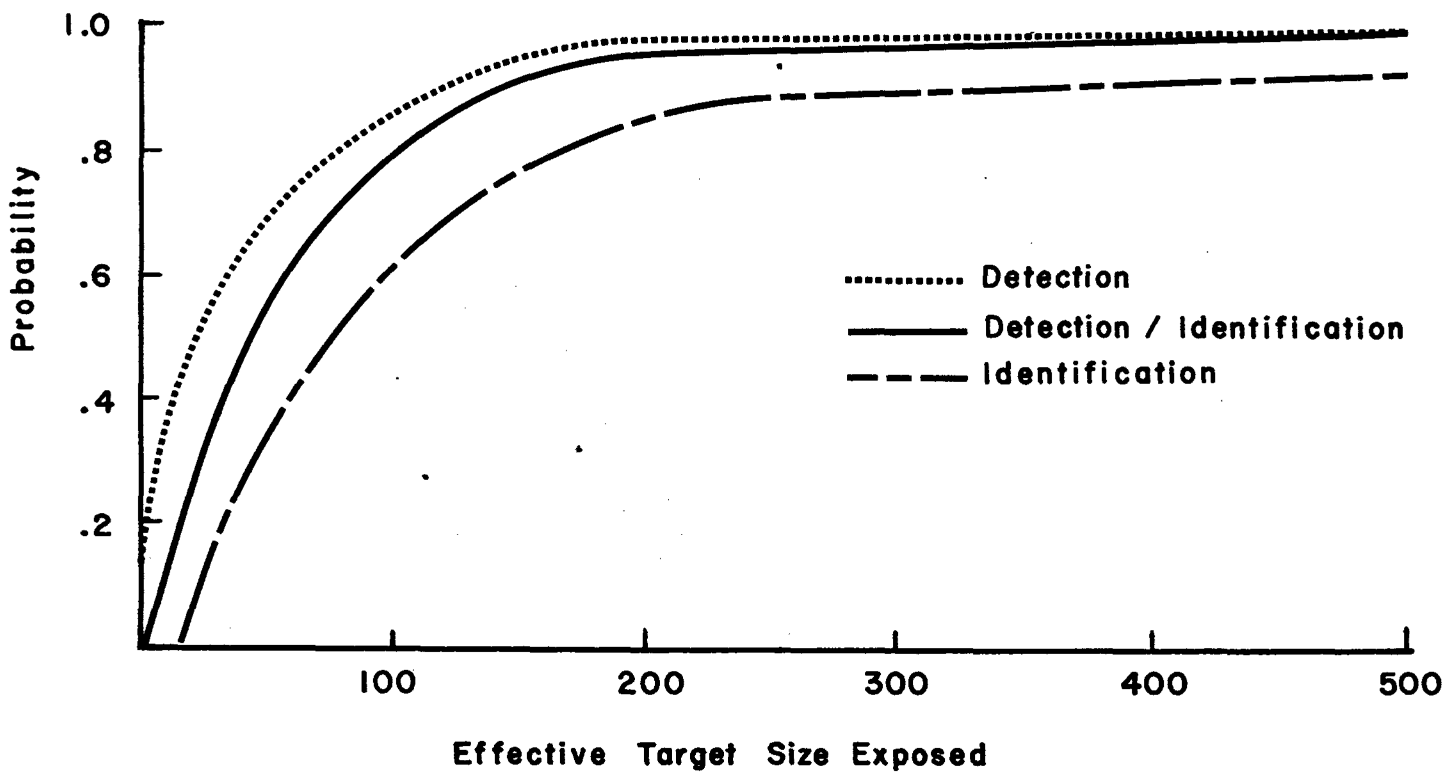


Figure 21. Probabilities of detection, detection/identification, and identification as a function of effective target size exposed. The curves are based on data from Whittenburg, _et al._, (1959a).

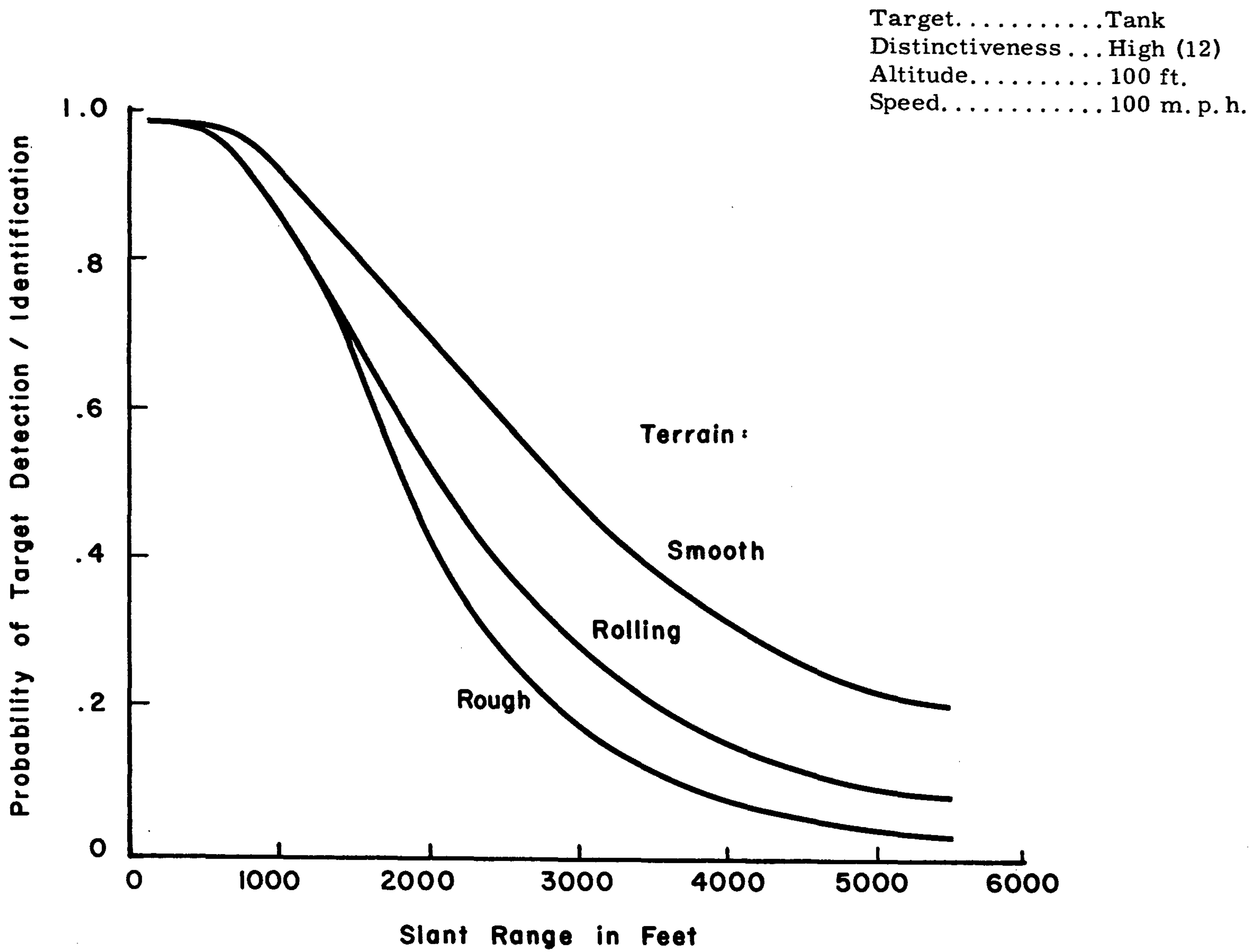


Figure 22. Probability of target detection/identification as a function of slant range and terrain type.

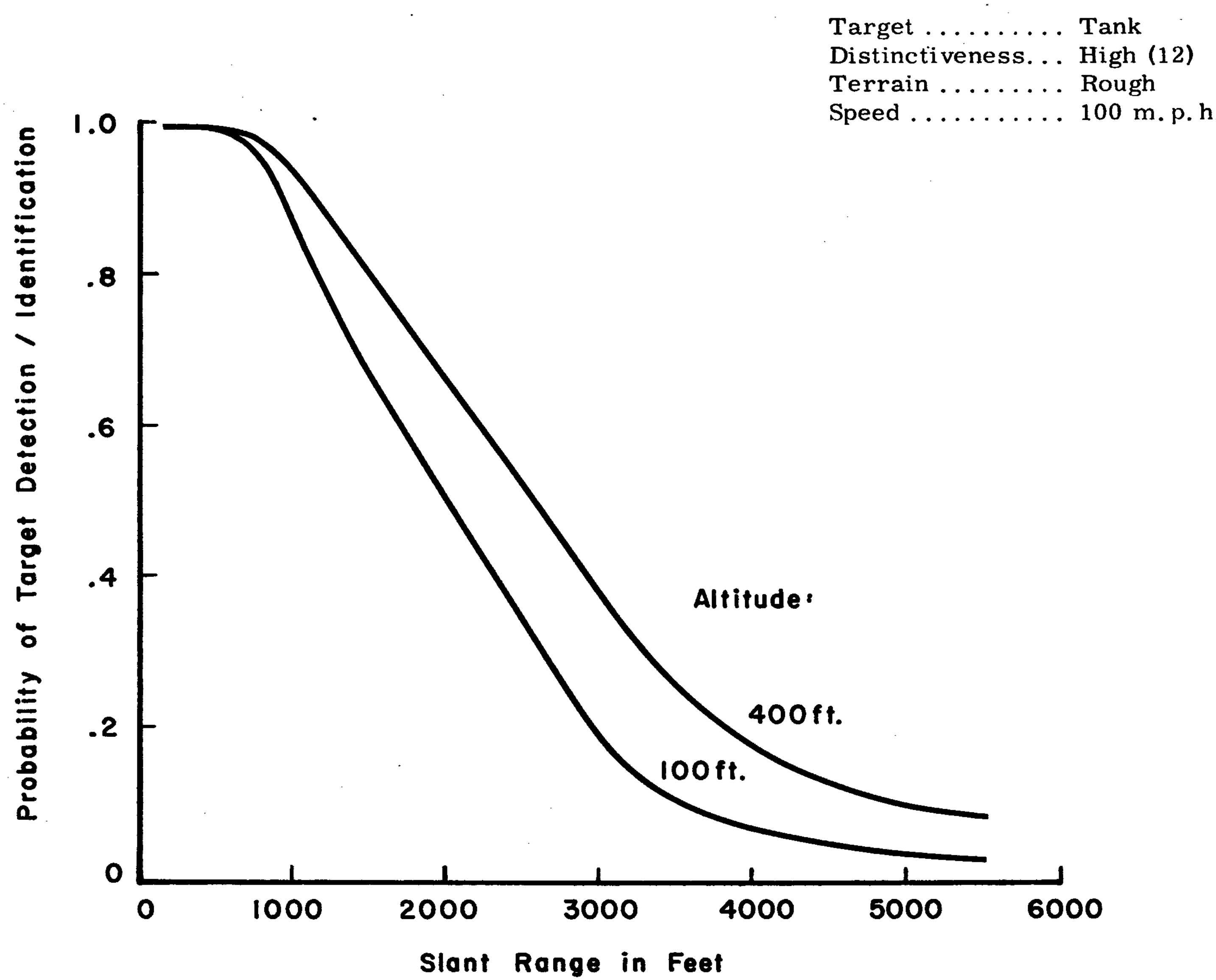


Figure 23. Probability of target detection/identification as a function of slant range and altitude.

Target . . . . Tank
Terrain . . . Rolling
Altitude . . . 100 ft.
Speed . . . . . 100 m. p. h.

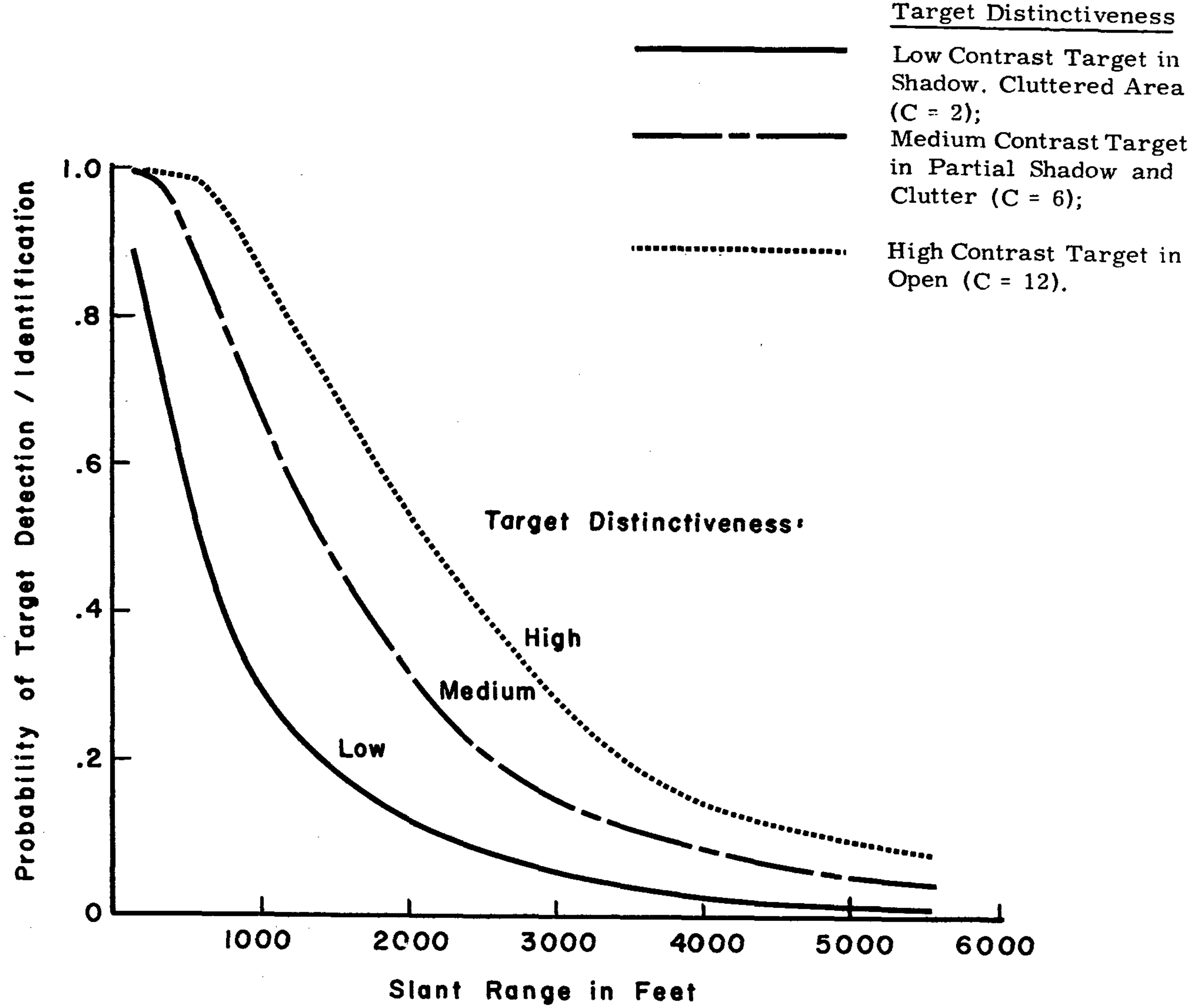


Figure 24. Probability of target detection/identification as a function of slant range and target distinctiveness.

To work out the predictions in the above Figures, estimates of six variables were required--slant range, aircraft altitude, aircraft speed, target size, target distinctiveness, and terrain type. All predictions assume a side scan pattern and relatively inexperienced observers. Clear visibility and daylight are also assumed. These are the conditions found in the Whittenburg, et al., study.

As it now stands, the preliminary model should provide realistic predictions of detection/identification performance for the conditions outlined above, within ranges of aircraft altitude from 100-500 ft. and at speeds from 50-150 m.p.h.[8] Until more data can be obtained, the model should not be used to predict at altitudes below 100 ft. and above 500 ft., and at speeds greater than 150 m.p.h. Before the model is used, however, validation is necessary. Because the model has been based on a set of data which were not collected for the purpose of model-building, the preliminary findings of this report must be tested in a field study specifically designed to determine the effects of the model variables on detection/identification performance. It is anticipated that subsequent to preliminary model validation, and if the findings are promising, the model can be extended to cover a wider range of conditions, including: altitude--nap-of-earth to 3000 feet; speed--hover to 350 m.p.h.; scan pattern--front and side; and trained observers. The research necessary to extend the model is discussed below.

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[8] These altitude and speed ranges were selected on the basis of a general synthesis of available data, observer reports, and field experience. Little systematic data exist concerning "nap-of-the-earth" conditions (i. e., 5-75 feet). However, subjective reports plus the data that are available suggest the possibility that qualitative differences may be found when nap-of-the-earth is compared to "low altitude" observation (i. e., 100-500 feet). Also, above approximately 500-1000 feet and at speeds greater than about 150 miles per hour, both exposure time and target size appear to assume different relationships to detection/identification performance. Observers at higher altitudes begin to respond to target-produced cues to identify the nature of the target, and the relationship between exposure time and detection assumes an increasingly non-linear form.

Research Necessary for Model Extension

In order to develop a refined model which covers an extended range of conditions, four research steps must be carried out:

1. The target distinctiveness scale must be developed.

2. Basic data must be obtained on vegetation masking.

3. Data on the effects of target apparent size, distinctiveness, and exposure time must be obtained under conditions of altitudes from nap-of-the-earth to 3000 feet, and speeds from hover to 350 m.p.h., using both front and side scan patterns.

4. The refined model must be developed, based on the findings in the above study, and validated in a subsequent field study.

The research necessary in each of these steps is discussed in more detail below.

Distinctiveness Scale Development

The first step in the research should be the development of a reference scale of target distinctiveness. In its final form, the reference scale should include a set of pictures and verbal descriptions of real targets in realistic placements on typical backgrounds. The set of target/ground combinations in the final scale will cover a wide range of distinctiveness that could be expected under actual operational conditions. To use the scale for prediction, the expected target would be compared with the pictures in the scale. The value of the picture most representative of the expected target would be selected as the distinctiveness value of that target.

To develop such a distinctiveness scale, it will be necessary to:

1. Define distinctiveness in terms of its underlying variables--brightness contrast, clutter, target shape, etc.

2. Specify all of the possible realistic operational conditions which reflect the underlying variables. For example, hue contrast depends on the

colors of the target and ground; it will be necessary to specify all of the realistic combinations of target/ground color that would be seen under operational conditions.

3. Obtain good color pictures of as many of the target/ground combinations as possible.

4. Using a psychometric scaling procedure, obtain scale values for each picture on distinctiveness, defining the term as the degree to which the target stands out from its background. Although the scaling procedure should be done on as many pictures as possible, the final reference scale will consist of only 10-20 pictures which cover the range of distinctiveness values in approximately equal steps.

Measurement of Vegetation Masking

At the present time, there are no data available on the probability of a line-of-sight to the ground when flying over different types of vegetation. Vegetation masking should be important in determining the effective exposure time of a target, particularly at extremely low altitudes, where the target may be intermittently masked. To conduct a field study of vegetation masking, it will be necessary first to define and select a number of types of vegetation for testing. Then, after sites with the representative types of vegetation are selected, direct aerial measurements will be made of the percentage of ground in line-of-sight from each of a number of given altitudes as a function of each type of vegetation. The final outcome of this study will be a series of graphs, showing probability of a line-of-sight as a function of altitude and type of vegetation. With this information, the effects of vegetation masking, as well as terrain masking, can be included in the estimation of effective exposure time in the final model.

Field Study of Size, Distinctiveness, and Time

This study must be done to obtain data which will extend the model to cover conditions of altitudes from nap-of-the-earth to 3000 feet, speeds from hover to 350 m.p.h., and both front and side scan patterns. In the study, target apparent size, distinctiveness, and effective exposure time will be systematically controlled and varied under conditions of varying aircraft altitude, speed, and observer scan pattern. The effects of each composite variable on identification of tactical targets by class, type, and name will be measured, using aerial observers who have received standard training.

Development and Validation of the Refined Model

Using statistical techniques, the data from the above field study will be used to construct the refined model. If all of the data cannot be subsumed under one model, a number of separate models will be developed. For example, depending on the results of the field study, separate models may be necessary to account for detection/identification performance at nap-of-the-earth flight and at higher altitudes. Also, separate models may be required for each of the response levels tested.

Finally, predictions from the refined model will be made and tested on a new set of field data. If the model predictions correspond to the new data, the model will be considered valid for operational use. If predictions are not in line with the data, the model will be revised and retested.

Summary

The objective of the present study was to develop a simple, operational model for predicting air-to-ground visual detection/identification of tactical targets. The model, based on data from the literature, was limited to conditions of daylight and clear visibility. A review of studies on target detection was made and major trends in the findings on a number of variables are presented in this report.

A preliminary model was developed using data from a field study (Whittenburg, et al., 1959a) of air-to-ground detection/identification of

tactical targets. Variables to be included in the model were selected from a list of variables found to be important in previous studies. The model includes estimates of eight input variables--target size, target shape, target/ground contrast, clutter, terrain type, aircraft altitude, aircraft speed, and range--which were grouped into three composite variables (target apparent size, target distinctiveness, and effective exposure time).

Because the preliminary model was based on data which were not collected for the purpose of model development, additional field studies must be conducted to develop and validate a refined model. The research necessary to validate and extend the model is described in the final section of the report.

A numerial summary of relevant studies on target detection/identification and a description of model calculations are presented in a separately bound set of appendices.

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RESEARCH ON VISUAL TARGET DETECTION

APPENDICES

TO

PART I: DEVELOPMENT OF AN AIR-TO-GROUND DETECTION/IDENTIFICATION MODEL

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APPENDIX A

Numerical Summary of Relevant Studies

This Appendix contains a summary of the variables studied in each of the 100 references selected as relevant to model development.

In the survey of the literature conducted as part of the present study, approximately 535 references were identified as being at least somewhat relevant to the general problem of visual target detection/identification. These included laboratory studies of visual capabilities, field studies of aerial observation, simulations, analytic studies, models for predicting detection probabilities and ranges, methodological studies, reviews of the literature, and discussions of problems in current and future detection systems. Of the 535 references, 100 were selected as especially relevant for model development. These included:

1. All field studies in which some variable related to detection/identification was systematically studied.

2. All analytical studies in which a variable related to detection/identification was studied.

3. All models for predicting detection/identification performance.

4. Those laboratory studies and simulations in which the authors attempted to relate laboratory variables and findings to the field situation.

The 100 references in this summary include 26 laboratory studies, 31 field studies, 39 models and analytic studies, and 4 reports which were combinations of two of these three types of studies. For the purposes of this summary, simulations were classified as one of the above three types of studies, depending on which type was most appropriate to the particular simulation study.

To summarize the research of these 100 studies, the matrices on the following pages were set up. The matrices contain a description of each reference according to variables studied and conditions of the study. Variables studied have been grouped into those concerned with characteristics of the target, target/ground, outside environment, aircraft, observer, and task. Secondary variables, which include combinations of single variables, are also included. Study conditions have been defined in each matrix. Within the matrix, the call number of each of the 100 studies is printed in the cells appropriate to describe that study. For example, suppose Study No. 1 varied aircraft speed and target size under field study conditions of daylight, clear visibility, and low altitude flight. The number "1" would be found, then, in six different cells--the combinations of the two variables and the three study conditions. The call numbers are further coded with an asterisk to indicate that a variable was studied and found non-significant.

Three matrices are presented on the following pages--one for laboratory studies (I), field studies (II), and models and analytical studies (III). On the pages following the matrices, the 100 studies are listed in order by call numbers.

The matrix may be used to find studies which investigated particular variables under various conditions. For example, to find whether any of the 100 studies was a field study of air-to-ground identification of target/ground contrast, turn to Section II and read down from the target/ground contrast variable until its intersection with the "identification" and the "air-to-ground" conditions. Any numbers which appear in both of these cells represent field studies of air-to-ground identification of targets varying in contrast.

Another example: to find models which were developed for high altitude conditions, turn to Section III, and read across on the line representing high altitude. If a model was developed to apply to any altitude, its call number will also appear opposite nap-of-earth, low, and medium altitudes. However, if the model applies particularly to high altitudes, its number will be listed only opposite high altitude. The call number of the model will appear on the "high altitude" line under each variable which was included in it. For example, if a high altitude model included the variables--target size, visibility, and aircraft speed, its number would be found on the high altitude line under each of those three variables. Actually, most models included a large number of variables and apply to a wide range of conditions. Thus, each study call number may appear in many places in a matrix.

I. LABORATORY STUDIES

	TARGET CHARACTERISTICS			
	Size	Shape	Context	Orientation
CONDITIONS				
Type of Target				
Artificial	43, 60, 84, 91, 100	43, *83, 91	38	
Military Object, Mobile		156		240
Other Military Object				
Contrast				
High (>80%)	43, 84, 100	43, 156		240
Med (20-80%)	100	156		240
Low (<20%)	43, 60, 100	43, 156		240
Camouflage				
Target Motion	84			
Target Density				
Low (single)				
High (grouped)	43	43	38	
Background Homogeneity				
Homogeneous	84, 100		38	
Heterogeneous	84		38	
Type of Terrain				
Level				
Rolling				
Rough				
Amt. of Vegetation				
Sparse				
Occasional				
Heavy				
Illumination				
Daylight (>100 ft. l.)	100			
Twilight & Night (<1 ft. l.)	60	156		240
Cloud Cover				
Visibility				
Clear (20 miles)				240
Lt. Haze (10-19 miles)				240
Low (below 9 miles)	60			240
Altitude				
Nap of Earth				
Low (100-500)				
Med (501-5000)				
High (Above 5000)			38	
Speed				
Slow (below 100 mph)				
Med (101-299 mph)				
High (over 300 mph)				
Type of Aircraft				
Light Planes				
Jets				
Observer Experience				
None				
Training or Experience				
Briefing, Knowledge				
None or Slight				
Thorough				
Load on Observer				
Heavy				
Light				
Response Required				
Detection	43, 60, 84, 91	43, 91	38	240
Recognition	43, 60, 91	43, 91, 156		
Identification				
Type of TDI				
Air to Ground		156		
Air to Air				
Ground to Air				
Ground to Ground				
Display & Photos	84		38	240

TARGET / GROUND CHARACTERISTICS

Brightness - Contrast	No. of Objects	No. of Targets Density	Structure of Field
*43, 44, 56, 60, *98, 100, 209	44, 186, 195, 209, 244	38, 43, 251	*84, 244
156, 240			
*43, 100, 156, 209, 240	186, 209, 244	43	*84, 244
*98, 100, 156, 209, 240	186, 209		
*43, 56, 60, 100, 156, 209, 240	186, 209	43	
		251	*84
		251	
*43		38, 43, 251	38
100	44, 186	38	*84
		38	*84
100, 240			
60, 156			
240			
240			
60, 240			
		38	38
56			
*43, 56, 60, 240	195	38, 43, 251	
*43, 60, 156	44, 186, 244	43	*84, 244
156	195		
56, 209, 240	209, 244	38, 251	*84, 244

I. LABORATORY STUDIES

	TARGET / GROUND CHARACTERISTICS		
	Homo-Heterog of Background	Luminance of Background	Similarity of Object to Target
CONDITIONS			
Type of Target			
Artificial	38	100	209
Military Object, Mobile			
Other Military Object			
Contrast			
High (>80%)		100	209
Med (20-80%)		100	209
Low (<20%)		100	209
Camouflage			
Target Motion			
Target Density			
Low (single)			
High (grouped)			
Background Homogeneity			
Homogeneous	38	100	
Heterogeneous	38		
Type of Terrain			
Level			
Rolling			
Rough			
Amt. of Vegetation			
Sparse			
Occasional			
Heavy			
Illumination			
Daylight (>100 ft. l.)		100	
Twilight & Night (<1 ft. l.)			
Cloud Cover			
Visibility			
Clear (20 miles)			
Lt. Haze (10-19 miles)			
Low (below 9 miles)			
Altitude			
Nap of Earth			
Low (100-500)			
Med (501-5000)			
High (Above 5000)			
Speed			
Slow (below 100 mph)			
Med (101-299 mph)			
High (over 300 mph)			
Type of Aircraft			
Light Planes			
Jets			
Observer Experience			
None			
Training or Experience			
Briefing, Knowledge			
None or Slight			
Thorough			
Load on Observer			
Heavy			
Light			
Response Required			
Detection	38		
Recognition			
Identification			
Type of TDI			
Air to Ground			
Air to Air			
Ground to Air			
Ground to Ground			
Display & Photos	38		209

	CHARACTERISTICS OF OUTSIDE ENVIRONMENT			AIRCRAFT CHARACTERISTICS
Sharpness Target Background Contour	Illumination - Sky Brightness	Angle of Sun	Atmospheric Atten/Transmit Meteorological Range	Altitude
91,242	101		56,60	
240	77,156	77		269,270
240	156			
240	156			
240	156		56,60	
	77	77		
240	77,101	77		269,270
	77,101,156	77	60	
240				
240				
240			60	
				269,270
				269,270
				269,270
				269,270
			56	269,270
				269,270
91,240,242	77	77	56,60	269,270
91	156		60	
	77	77		
	156			269,270
	77	77		
240,242			56	

I. LABORATORY STUDIES

	AIRCRAFT CHARACTERISTICS			OBSERVER CHARACTERISTICS	
	Range	Approach Angle	Speed	Visual Skills	Training and Experience
CONDITIONS					
Type of Target					
Artificial	43, 44, 186			56, 98, 244	24, 268
Military Object, Mobile	77	240, 270	269, *270		269
Other Military Object					
Contrast					
High (>80%)	43, 186	240		244	
Med (20-80%)	186	240		98	
Low (<20%)	43, 186	240		56	
Camouflage					
Target Motion					
Target Density					
Low (single)					
High (grouped)	43				
Background Homogeneity					
Homogeneous					
Heterogeneous	44, 186				
Type of Terrain					
Level					
Rolling					
Rough					
Amt. of Vegetation					
Sparse					
Occasional	77				
Heavy					
Illumination					
Daylight (>100 ft. l.)	77	240, 270	269, *270		269
Twilight & Night (<1 ft. l.)	77				
Cloud Cover					
Visibility					
Clear (20 miles)		240			
Lt. Haze (10-19 miles)		240			
Low (below 9 miles)		240			
Altitude					
Nap of Earth					
Low (100-500)		270	269, *270		269
Med (501-5000)					
High (Above 5000)					
Speed					
Slow (below 100 mph)					
Med (101-299 mph)					
High (over 300 mph)		270	269, *270		269
Type of Aircraft					
Light Planes					
Jets		270	269, *270		269
Observer Experience					
None		270	269, *270		269
Training or Experience		270	269, *270	56	269
Briefing, Knowledge					
None or Slight					
Thorough		270	269, *270		269
Load on Observer					
Heavy					
Light					
Response Required					
Detection	43, 77	240, 270	269, *270	244	24, 268, 269
Recognition	43, 44, 186				
Identification	77				
Type of TDI					
Air to Ground		270	269, 270	56	24, 269
Air to Air					
Ground to Air					
Ground to Ground	77				
Display & Photos		240		56, 244	

	TASK CHARACTERISTICS			SECONDARY VARIABLES
Knowledge About Expected Target	Search & Scan Techniques	Size of Field Searched	Miscellaneous, Equipment, No. of Observers	Apparent Contrast
267	98		101	186
		100, 243		
		100		186
	98	100		186
		100		186
		100		
				186
		100	101	
			101	
267		243		
				186
		243		

I. LABORATORY STUDIES

	SECONDARY VARIABLES	
	Apparent Motion	Apparent Size
CONDITIONS		
Type of Target		
Artificial	24,251	43,44,186,209
Military Object, Mobile		156
Other Military Object		
Contrast		
High (>80%)		43,156,186,209
Med (20-80%)		156,186
Low (<20%)		43,156,186
Camouflage		
Target Motion	251	
Target Density		
Low (single)	251	
High (grouped)	251	43
Background Homogeneity		
Homogeneous		
Heterogeneous		44,186
Type of Terrain		
Level		
Rolling		
Rough		
Amt. of Vegetation		
Sparse		
Occasional		
Heavy		
Illumination		
Daylight (>100 ft. l.)		
Twilight & Night (<1 ft. l.)		156
Cloud Cover		
Visibility		
Clear (20 miles)		
Lt. Haze (10-19 miles)		
Low (below 9 miles)		
Altitude		
Nap of Earth		
Low (100-500)		
Med (501-5000)		
High (Above 5000)		
Speed		
Slow (below 100 mph)		
Med (101-299 mph)		
High (over 300 mph)		
Type of Aircraft		
Light Planes		
Jets		
Observer Experience		
None		
Training or Experience		
Briefing, Knowledge		
None or Slight		
Thorough		
Load on Observer		
Heavy		
Light		
Response Required		
Detection	24,251	43
Recognition		43,44,156,186
Identification		
Type of TDI		
Air to Ground	24	156
Air to Air		
Ground to Air		
Ground to Ground		
Display & Photos	251	209

SECONDARY VARIABLES

Exposure Time	
24,43,44,60,84,209,244,246,247	
240	
43,84,209,240,244	
240	
43,60,240	
84,246	
43	
84	
44,84	
240	
60	
240	
240	
60,240	
24,43,60,240,244,246,247	
43,44,60	
24,84	
84,209,240,244,246,247	

II. FIELD STUDIES

TARGET CHARACTERISTICS

CONDITIONS	Size	Shape
Type of Target		
Artificial	147,184,257	184,229
Military Object, Mobile	1,132,160,163,183,202	163,164,202
Other Military Object	1,163,183	163
Contrast		
High (>80%)	184,202,257	184,202,229
Med (20-80%)	132,184,202,257	184,202,229
Low (<20%)	202,257	202
Camouflage	1,160	
Target Motion	1,202	164,202
Target Density		
Low (single)	147,160	
High (grouped)	1,160	
Background Homogeneity		
Homogeneous		
Heterogeneous		
Type of Terrain		
Level	132,163,183,184	163,164,184,229
Rolling	147,163	163
Rough	163	163
Amt. of Vegetation		
Sparse	147,183	164
Occasional	132,160,163,184	163,184
Heavy	160	
Illumination		
Daylight (>100 ft. l.)	1,132,147,160,163,183,184,202,257	163,164,184,202,229
Twilight & Night (<1 ft. l.)		
Cloud Cover	132,160	
Visibility		
Clear (20 miles)	132,160,183,184,257	164,184,229
Lt. Haze (10-19 miles)	160	229
Low (below 9 miles)		229
Altitude		
Nap of Earth	147,163,183	163
Low (100-500)	132,147,163,183,184	163,184
Med (501-5000)	147,160	163,229
High (Above 5000)	1,147,160,202	202,229
Speed		
Slow (below 100 mph)	132,163,184,202	163,184,202,229
Med (101-299 mph)	160,202	202
High (over 300 mph)	1,160,202	202
Type of Aircraft		
Light Planes	132,163	163,229
Jets	1,160	164
Observer Experience		
None	132,183	
Training or Experience	1,132,160,163	163
Briefing, Knowledge		
None or Slight	132,183	164
Thorough	1,163	163,229
Load on Observer		
Heavy		
Light	132,163,183,184	163,184,229
Response Required		
Detection	1,132,147,160,163,202,257	163,164,202,229
Recognition	160,183	
Identification	1,132,163,184	163,164,184,229
Type of TDI		
Air to Ground	1,132,147,160,163,183,184,202	163,184,202,229
Air to Air		
Ground to Air		164
Ground to Ground	257	
Display & Photos		

TARGET CHARACTERISTICS				TARGET / GROUND CHARACTERISTICS		
Motion	Color	Luminance Reflectance	Target Generated Cues	Brightness Contrast	Camouflage	Shadow
		241		241		
1,258	202	202	230	*132,202	230	*132,*163
1		83				*163
258	202	202,241		202,241		
	202	202,241		*132,202,241		*132
	202	202,241		202,241		
1			230		230	
1,258	202	202	230	202	230	
1			230		230	
258				*132		*132,*163
						*163
						*163
258			230		230	
				*132		*132,*163
			230		230	
1,258	202	83,202,241	230	*132,202,241	230	*132,*163
				*132		*132
258		241	230	*132,241	230	*132
258		241		241		
258		241		241		
				*132		*163
258						*132,*163
			230		230	
1	202	202		202	230	
	202	202		*132,202		*132,*163
258	202	202		202		
1,258	202	202	230	202		
				*132		*132,*163
1,258			230		230	
				*132		*132
1				*132		*132,*163
258				*132		*132
1,258						*163
258						
258				*132		*132,*163
1,258	202	202,241	230	*132,202,241	230	*132,*163
1				*132		*132,*163
1,258	202	202	230	*132,202	230	*132,*163
		83				
		241		241		
			230		230	

TARGET / GROUND CHARACTERISTICS

CONDITIONS	No. of Objects	No. of Targets Density	Luminance of Background	Illumination - Sky Brightness
Type of Target				
Artificial				241
Military Object, Mobile	*134	1, *132, 160		*132, *137
Other Military Object		1	202	83
Contrast				
High (>80%)			202	241
Med (20-80%)	*134	*132	202	*132, *137, 241
Low (<20%)			202	241
Camouflage		1, 160		
Target Motion		1	202	
Target Density				
Low (single)		160		
High (grouped)		1, 160		
Background Homogeneity				
Homogeneous				
Heterogeneous				
Type of Terrain				
Level	*134	*132		*132, *137
Rolling				
Rough				
Amt. of Vegetation				
Sparse				*137
Occasional	*134	*132, 160		*132
Heavy		160		
Illumination				
Daylight (>100 ft. l.)	*134	1, *132, 160	202	83, *132, *137, 241
Twilight & Night (<1 ft. l.)				
Cloud Cover		*132, 160		*132
Visibility				
Clear (20 miles)	*134	*132, 160		*132, *137, 241
Lt. Haze (10-19 miles)		160		241
Low (below 9 miles)				241
Altitude				
Nap of Earth				
Low (100-500)	*134	*132		*132
Med (501-5000)		160		*137
High (Above 5000)		1, 160	202	
Speed				
Slow (below 100 mph)	*134	*132	202	*132, *137
Med (101-299 mph)		160	202	
High (over 300 mph)		1, 160		
Type of Aircraft				
Light Planes	*134	*132		*132, *137
Jets		1, 160		
Observer Experience				
None	*134	*132		*132, *137
Training or Experience	*134	1, *132, 160		*132, *137
Briefing, Knowledge				
None or Slight	*134	*132		*132
Thorough		1		*137
Load on Observer				
Heavy		*132		
Light	*134			*132, *137
Response Required				
Detection		1, *132, 160	202	*132, 241
Recognition		160		
Identification	*134	1, *132		*132, *137
Type of TDI				
Air to Ground	*134	1, *132, 160	202	*132, *137
Air to Air				83
Ground to Air				
Ground to Ground				241
Display & Photos				

CHARACTERISTICS OF OUTSIDE ENVIRONMENT

Angle of Sun	Atmospheric Atten/Transmit Meteorological Range	Terrain Types	Type of Vegetation
229	229,241		147,184
154,*163	202,258	164	1,93,103,230
83,*163			
229	202,229,241,258		184
229	202,229,241		184
	202,241		
			230
	202,258	164	230
			147
154			230
154,*163,229	229,258	164	184
*163			147
*163			
	258	164	147,230
154,*163			93,184
			93,103,230
83,154,*163,229	202,229,241,258	164	103,147,184,230
			103
154,229	229,241,258	164	184,230
229	229,241,258		
	229,241,258		
*163			147
*163	258		147,184
154,229	229	164	147,230
154,229	202,229		147
*163,229	202,229		184
154	202,258		
	202,258		230
154,*163,229	229		
	258	164	230
154,*163			
	258	164	
154,*163,229	229,258		
	258		
*163,229	229,258		184
*163,229	202,229,241,258	164	93,103,147,230
154			184
*163,229	229	164	
154,*163,229	202,229,258		147,184,230
83			
		164	
	241		93,103
			230

II. FIELD STUDIES

AIRCRAFT CHARACTERISTICS

CONDITIONS	Altitude
Type of Target	
Artificial	147
Military Object, Mobile	1, 19, 145, 154, 160, 164, 183, 258
Other Military Object	1, 183
Contrast	
High (>80%)	258
Med (20-80%)	
Low (<20%)	19
Camouflage	1, 160
Target Motion	1, 164, 258
Target Density	
Low (single)	9, 19, 145, 147, 160
High (grouped)	1, 154, 160
Background Homogeneity	
Homogeneous	19
Heterogeneous	
Type of Terrain	
Level	19, 154, 164, 183, 258
Rolling	147
Rough	
Amt. of Vegetation	
Sparse	19, 147, 164, 183, 258
Occasional	9, 154, 160
Heavy	160
Illumination	
Daylight (>100 ft. l.)	1, 9, 19, 145, 147, 154, 160, 164, 183, 258
Twilight & Night (<1 ft. l.)	
Cloud Cover	160
Visibility	
Clear (20 miles)	19, 154, 160, 164, 183, 258
Lt. Haze (10-19 miles)	160, 258
Low (below 9 miles)	258
Altitude	
Nap of Earth	9, 145, 147, 183
Low (100-500)	9, 145, 147, 183, 258
Med (501-5000)	19, 147, 154, 160, 164
High (Above 5000)	1, 147, 154, 160
Speed	
Slow (below 100 mph)	
Med (101-299 mph)	19, 154, 160, 258
High (over 300 mph)	1, 160, 258
Type of Aircraft	
Light Planes	9, 145, 154
Jets	1, 160, 164, 258
Observer Experience	
None	183
Training or Experience	1, 19, 154, 160
Briefing, Knowledge	
None or Slight	164, 183, 258
Thorough	1, 154, 258
Load on Observer	
Heavy	258
Light	19, 183, 258
Response Required	
Detection	1, 9, 19, 145, 147, 160, 164, 258
Recognition	19, 154, 160, 183
Identification	1, 164
Type of TDI	
Air to Ground	1, 19, 147, 154, 160, 183, 258
Air to Air	
Ground to Air	9, 145, 164
Ground to Ground	
Display & Photos	

AIRCRAFT CHARACTERISTICS

Range	Approach Angle
147, 184, 229, 241, 257	
9, 133, 137, 145, 154, 163, 202	*132, 133, 134, 137, 202, 233
163	
184, 202, 229, 241, 257	202
133, 137, 184, 202, 229, 241, 257	*132, 133, 134, 137, 202
19, 202, 241, 257	202
202	202, 233
9, 19, 145, 147	
154	
19	
19, 133, 137, 154, 163, 184, 229	*132, 133, 134, 137
147, 163	
163	
19, 133, 137, 147	133, 137
9, 154, 163, 184	*132, 134
9, 19, 133, 137, 145, 147, 154, 163, 184, 202, 229, 241, 257	*132, 133, 134, 137, 202, 233
	*132
19, 133, 137, 154, 184, 229, 241, 257	*132, 133, 134, 137, 233
229, 241	
229, 241	
9, 145, 147, 163	
9, 145, 147, 163, 184	*132, 134
19, 133, 137, 147, 154, 229	133, 137
147, 154, 202, 229	202
133, 137, 163, 184, 202, 229	*132, 133, 134, 137, 202, 233
19, 154, 202	202, 233
202	202
9, 133, 137, 145, 154, 163, 229	*132, 133, 134, 137
133, 137	*132, 133, 134, 137
19, 133, 137, 154, 163	*132, 133, 134, 137
	*132, 134, 233
133, 137, 154, 163, 229	133, 137, 233
	233
19, 133, 137, 163, 184, 229	*132, 133, 134, 137
9, 19, 145, 147, 163, 202, 229, 241, 257	*132, 202, 233
19, 154, 184	
133, 137, 163, 229	*132, 133, 134, 137
19, 133, 137, 147, 154, 163, 184, 202, 229	*132, 133, 134, 137, 202
	233
9, 145	
241, 257	

II. FIELD STUDIES

AIRCRAFT CHARACTERISTICS

CONDITIONS	Speed	Search Pattern
Type of Target		
Artificial	*184, 245	
Military Object, Mobile	21, 137, *160, 182, 202, 239, 258	160
Other Military Object	533	
Contrast		
High (>80%)	*184, 202, 258	
Med (20-80%)	*137, *184, 202	
Low (<20%)	202	
Camouflage	*160, 182	160
Target Motion	202, 258	
Target Density		
Low (single)	*160	160
High (grouped)	*160	160
Background Homogeneity		
Homogeneous		
Heterogeneous		
Type of Terrain		
Level	*137, *184, 258	
Rolling		
Rough		
Amt. of Vegetation		
Sparse	*137, 258	
Occasional	*160, *184	160
Heavy	*160	160
Illumination		
Daylight (>100 ft. 1.)	21, *137, *160, *184, 202, 239, 245, 258, 533	160
Twilight & Night (<1 ft. 1.)		
Cloud Cover	*160	160
Visibility		
Clear (20 miles)	21, *137, *160, *184, 239, 245, 258, 533	160
Lt. Haze (10-19 miles)	*160, 258	160
Low (below 9 miles)	258	
Altitude		
Nap of Earth		
Low (100-500)	21, 182, *184, 239, 245, 258, 533	
Med (501-5000)	*137, *160	160
High (Above 5000)	*160, 202	160
Speed		
Slow (below 100 mph)	21, *137, *184, 202	
Med (101-299 mph)	21, *160, 202, 245, 258, 533	160
High (over 300 mph)	*160, 182, 202, 239, 245, 258, 533	160
Type of Aircraft		
Light Planes	*137	
Jets	*160, 182, 239, 258	160
Observer Experience		
None	*137, 182	
Training or Experience	*137, *160, 182	160
Briefing, Knowledge		
None or Slight	258, 533	
Thorough	*137, 258, 533	
Load on Observer		
Heavy	182, 258	
Light	*137, 182, *184, 258	
Response Required		
Detection	21, *160, 202, 239, 245, 258	160
Recognition	21, *160, *184, 533	160
Identification	*137, 182	
Type of TDI		
Air to Ground	21, *137, *160, 182, *184, 202, 239, 245, 258, 533	160
Air to Air		
Ground to Air		
Ground to Ground		
Display & Photos		

OBSERVER CHARACTERISTICS				TASK CHARACTERISTICS
Vibration	Visual Skills	Training and Experience	Knowledge About Expected Target	Task Requirements
	245			
182		1, 132, 133, 137, 182, *238	*233	*160, 182, 258, 265
		1		
				258
		132, 133, 137		
182		1, 182		*160, 182
		1	*233	258
				*160
		1		*160
		132, 133, 137, *238		258
		133, 137, *238		258
		132		*160
				*160
	245	1, 132, 133, 137, *238	*233	*160, 258, 265
		132		*160
	245	132, 133, 137, *238	*233	*160, 258, 265
				*160, 258
				258
*182	245	132, 182, *238		182, 258
		133, 137	164	*160
		1		*160
		132, 133, 137	*233	
	245		*233	*160, 258
*182	245	1, 182, *238		*160, 182, 258
		132, 133, 137		
*182		1, 182		*160, 182, 258
		132, 133, 137, 182		182
*182		1, 132, 182, *238		*160, 182
		132	*233	258
		1, 133, 137	*233	258
*182		182	*233	182, 258
*182		132, 133, 137, 182, *238		182, 258
	245	1, 132	*233	*160, 258, 265
				*160
*182		1, 132, 133, 137, 182, *238		182
	245	1, 132, 133, 137, 182, *238		*160, 182, 258, 265
			*233	
		133		

II. FIELD STUDIES

TASK CHARACTERISTICS

	Search & Scan Techniques	Size of Field Searched	Miscellaneous, Equipment, No. of Observers
CONDITIONS			
Type of Target			
Artificial			257
Military Object, Mobile	19, 21, 202	164, 227, 258	1, 145, 265
Other Military Object		533	1
Contrast			
High (>80%)	202	258	257
Med (20-80%)	202		257
Low (<20%)	19, 202		257
Camouflage		227	1
Target Motion	202	164, 258	1
Target Density			
Low (single)	19		145
High (grouped)			1
Background Homogeneity			
Homogeneous	19		
Heterogeneous			
Type of Terrain			
Level	19	164, 227, 258	
Rolling		227	
Rough		227	
Amt. of Vegetation			
Sparse	19	164, 227, 258	
Occasional			
Heavy			
Illumination			
Daylight (>100 ft. 1.)	19, 21, 202	164,227,258,533	1, 145, 257, 265
Twilight & Night (<1 ft. 1.)			
Cloud Cover			
Visibility			
Clear (20 miles)	19, 21	164,227,258,533	257, 265
Lt. Haze (10-19 miles)		258	
Low (below 9 miles)		258	
Altitude			
Nap of Earth		227	145
Low (100-500)	21	258, 533	145
Med (501-5000)	19		
High (Above 5000)	202, 265		1
Speed			
Slow (below 100 mph)	21, 202		
Med (101-299 mph)	19, 21, 202	258, 533	
High (over 300 mph)	202	258, 533	1
Type of Aircraft			
Light Planes		227	145
Jets		164, 258	1
Observer Experience			
None			
Training or Experience	19		1
Briefing, Knowledge			
None or Slight		164,227,258,533	
Thorough		227, 258, 533	1
Load on Observer			
Heavy		227, 258	
Light	19	258	
Response Required			
Detection	19, 21, 202	164, 227, 258	1, 145, 257, 265
Recognition	19, 21	533	
Identification		164, 227	1
Type of TDI			
Air to Ground	19, 21, 202	227, 258, 533	1, 265
Air to Air			
Ground to Air		164	145
Ground to Ground			257
Display & Photos			

SECONDARY VARIABLES

Apparent Motion	Apparent Size	Exposure Time	
245			
	134,137	132,137	
	83		
	134,137	132,137	
	134,137	132,137	
	137	137	
	134	132	
245	83,134,137	132,137	
		132	
245	134,137	132,137	
245	134	132	
	137	137	
	134,137	132,137	
245			
245			
	134,137	132,137	
	134,137	132,137	
	134,137	132,137	
	134	132	
	137	137	
	134,137	132,137	
245		132	
	134,137	132,137	
245	134,137	132,137	
	83		

	Size
CONDITIONS	
Type of Target	
Artificial	220,229
Military Object, Mobile	2,39,40,97,99,151,177,178,188,192,200,204,221,228,
Other Military Object	10,39,40
Contrast	
High (>80%)	2,155,188,200,220,221,229,237,254,256
Med (20-80%)	2,155,188,192,200,220,221,228,229,237,256
Low (<20%)	2,155,188,200,220,221,228,237,254,256
Camouflage	200
Target Motion	2,151,178,188,192,200,237
Target Density	
Low (single)	237
High (grouped)	237
Background Homogeneity	
Homogeneous	2,151
Heterogeneous	
Type of Terrain	
Level	149,200,221,229,256
Rolling	200,221,256
Rough	200,221,256
Amt. of Vegetation	
Sparse	149,221
Occasional	221
Heavy	221
Illumination	
Daylight (>100 ft. l.)	2,40,149,151,155,178,188,192,200,204,220,221,228,
Twilight & Night (<1 ft. l.)	99,151,204,220,228
Cloud Cover	204
Visibility	
Clear (20 miles)	2,149,151,178,188,192,200,204,220,221,229,237,254,
Lt. Haze (10-19 miles)	2,40,178,192,204,220,229,237,256
Low (below 9 miles)	2,192,204,220,229,237
Altitude	
Nap of Earth	40,192
Low (100-500)	39,40,155,192,200,204,205,221,256
Med (501-5000)	40,155,192,204,229,254
High (Above 5000)	2,10,40,99,151,155,177,192,204,229,237,254
Speed	
Slow (below 100 mph)	40,188,200,229,254
Med (101-299 mph)	40,178,188,200,254
High (over 300 mph)	10,39,40,178,188,200,205,228,237,254
Type of Aircraft	
Light Planes	97,200,204,221,229
Jets	10,200,237
Observer Experience	
None	
Training or Experience	40
Briefing, Knowledge	
None or Slight	
Thorough	229
Load on Observer	
Heavy	204
Light	40,204,229
Response Required	
Detection	2,10,39,40,97,99,148,149,155,177,178,188,192,196,
Recognition	10,39,149,256
Identification	40,148,221,229
Type of TDI	
Air to Ground	10,39,40,148,149,155,178,192,196,204,205,221,228,
Air to Air	2,97,99,151,177,188,228,237
Ground to Air	99,200,261
Ground to Ground	
Display & Photos	

TARGET CHARACTERISTICS

Size	Shape	Motion	Color
237,254,256,261	99,178	97,178	2,178
			2
			2
			2
	178	178	2,178
			2
	149		
	149		
229,237,254,256,261	149,178	178	2,178
	99		
256	149,178	178	2,178
	178	178	2,178
			2
	205		
	99		2
	178	178	178
	178,205	178	178
		97	
200,204,221,228,229,237,254,256,261	99,149,178,196	97,178,196	2,178
	149		
229,254,256	149,178,196,205	178,196	178
	99	97	2
	99		

III. MODELS AND ANALYTICAL STUDIES — TARGET CHARACTERISTICS

CONDITIONS	Context	Orientation	Luminance Reflectance	Brightness Contrast
Type of Target				
Artificial			113	15,113
Military Object, Mobile	40	2	178,200	2,39,97,99,177,
Other Military Object	40			39
Contrast				
High (>80%)		2	36,113,200	2,12,36,113,155,
Med (20-80%)		2	36,113,200	2,12,36,113,155,
Low (<20%)		2	36,113,200	2,12,36,113,155,
Camouflage			200	
Target Motion		2	178,200	2,178,188,206,
Target Density				
Low (single)				237
High (grouped)				237
Background Homogeneity				
Homogeneous		2		2,201
Heterogeneous				201
Type of Terrain				
Level			200	143,149,256
Rolling			200	143,201,256
Rough			200	143,256
Amt. of Vegetation				
Sparse				143,149,201
Occasional				143,201
Heavy				143,201
Illumination				
Daylight (>100 ft. 1.)	40	2	113,178,200	2,12,113,143,
Twilight & Night (<1 ft. 1.)			36,113	36,99,113,143,
Cloud Cover				
Visibility				
Clear (20 miles)	40	2	36,178,200	2,12,36,142,143,
Lt. Haze (10-19 miles)		2	36,178	2,12,36,142,143,
Low (below 9 miles)		2	36	2,12,36,142,143,
Altitude				
Nap of Earth	40			12,143
Low (100-500)	40		200,205	12,39,143,155,
Med (501-5000)	40		36	12,36,143,155,
High (Above 5000)	40	2		2,12,99,142,143,
Speed				
Slow (below 100 mph)	40		200	143,188,254
Med (101-299 mph)	40		178,200	143,188,201,254
High (over 300 mph)	40		178,200,205	39,143,188,228,
Type of Aircraft				
Light Planes			200	97
Jets			200	237
Observer Experience				
None				
Training or Experience	40			
Briefing, Knowledge				
None or Slight				
Thorough				
Load on Observer				
Heavy				
Light	40			
Response Required				
Detection	40,148	2	148,178,200	2,39,97,99,143,
Recognition				39,149,256
Identification	40,148		148	
Type of TDI				
Air to Ground	40,148		36,113,148,178,205	2,36,39,113,
Air to Air		2		97,99,177,188,
Ground to Air			200	99,261
Ground to Ground				
Display & Photos				

TARGET / GROUND CHARACTERISTICS

Brightness - Contrast	Shadow	No. of Objects	No. of Targets Density
		186	
178, 188, 201, 206, 228, 237, 254, 256, 261	221		39, 162, 221
			39, 162
188, 201, 206, 220, 237, 254, 256	221	186	221
188, 201, 206, 220, 228, 237, 256	221	186	221
188, 201, 206, 220, 228, 237, 254, 256	221	186	221
237			
		186	
	221	143	221
	221	143	221
	221	143	221
	221	143	221
	221	143	221
	221	143	221
149, 155, 178, 188, 201, 206, 220, 228, 237, 254, 256, 261	221	143	221
220, 228		143	
149, 178, 188, 201, 206, 220, 237, 254, 256	221	143, 186	221
178, 201, 206, 220, 237, 256		143, 186	
201, 206, 220, 237		143	
		143	
201, 256	221	143, 205	39, 221
178, 201, 254		143, 186	
155, 177, 178, 237, 254		143, 186	
		143, 186	
		143, 186	
237, 254		143, 186, 205	39
	221		221
149, 155, 177, 178, 188, 201, 206, 228, 237, 254, 256, 261	221	143	39, 162, 221
		186	39, 162
	221		221
142, 143, 149, 155, 178, 201, 206, 228, 254, 256	221	143, 186, 205	39, 221
228, 237			
			162

III. MODELS AND ANALYTICAL STUDIES

TARGET / GROUND CHARACTERISTICS

CONDITIONS	Homo-Heterog of Background	Luminance of Background	Similarity of Object to Target
Type of Target			
Artificial			
Military Object, Mobile	99, 201	39	39, 201
Other Military Object		39	39
Contrast			
High (>80%)	201		201
Med (20-80%)	201		201
Low (<20%)	201		201
Camouflage			
Target Motion			
Target Density			
Low (single)			
High (grouped)			
Background Homogeneity			
Homogeneous	201		201
Heterogeneous	201		201
Type of Terrain			
Level			
Rolling	201		201
Rough			
Amt. of Vegetation			
Sparse	201		201
Occasional	201		201
Heavy	201		201
Illumination			
Daylight (>100 ft. l.)	201		201
Twilight & Night (<1 ft. l.)	99		
Cloud Cover			
Visibility			
Clear (20 miles)	201	142	201
Lt. Haze (10-19 miles)	201	142	201
Low (below 9 miles)	201	142	201
Altitude			
Nap of Earth			
Low (100-500)	201	39	39, 201
Med (501-5000)	201		201
High (Above 5000)	99	142	
Speed			
Slow (below 100 mph)			
Med (101-299 mph)	201		201
High (over 300 mph)		39	39
Type of Aircraft			
Light Planes			
Jets			
Observer Experience			
None			
Training or Experience			
Briefing, Knowledge			
None or Slight			
Thorough			
Load on Observer			
Heavy			
Light			
Response Required			
Detection	99, 201	39, 148	39, 201
Recognition		39	39
Identification		148	
Type of TDI			
Air to Ground	201	39, 142, 148	39, 201
Air to Air	99		
Ground to Air	99		
Ground to Ground			
Display & Photos			

CHARACTERISTICS OF OUTSIDE ENVIRONMENT

Illumination - Sky Brightness	Sky-Ground Brightness Ratio
113,220,229	186
97,99,151,177,178,188,204,228	39,201,221,256
	39
36,113,188,220,229	155,186,201,221,256
36,113,188,220,228,229	155,186,201,221,256
36,113,188,220,228	155,186,201,221,256
151,178,188	
151	201
	186,201
143,149,229	143,221,256
143	143,201,221,256
143	143,221,256
143,149	143,201,221
143	143,201,221
143	143,201,221
37,113,143,149,151,178,188,204,220,228,229	143,155,201,221,256
36,99,113,143,151,204,220,228	143
204	
36,142,143,149,151,178,188,204,220,229	143,186,201,221,256
36,142,143,178,204,220,229	143,186,201,256
36,142,143,204,220,229	143,201
143	143
143,204	39,143,155,201,221,256
36,143,178,204,229	143,155,186,201
37,99,142,143,151,177,178,204,229	143,155,186
143,188,229	143,186
143,188	143,186,201
143,188,228	39,143,186
97,204,229	221
229	
204	
204,229	
97,99,143,149,177,178,188,196,204,228,229	39,143,148,155,201,221,256
149	39,186,256
229	148,221
36,113,142,143,149,178,196,204,228,229	39,143,148,155,186,201,221,256
97,99,151,177,188,228	
99	

III. MODELS AND ANALYTICAL STUDIES

CHARACTERISTICS OF OUTSIDE ENVIRONMENT

	Angle of Sun	Atmospheric Atten/Transmit Meteorological Range
CONDITIONS		
Type of Target		
Artificial		186, 220, 229
Military Object, Mobile	2, 151, 201, 204	2, 97, 99, 162, 177, 178, 188, 192,
Other Military Object		162
Contrast		
High (>80%)	2, 201	2, 12, 36, 155, 186, 188, 201, 206,
Med (20-80%)	2, 201	2, 12, 36, 155, 186, 188, 192, 201,
Low (<20%)	2, 201	2, 12, 155, 186, 188, 201, 206, 220,
Camouflage		
Target Motion	2, 151	2, 178, 188, 192, 206, 237
Target Density		
Low (single)		237
High (grouped)		237
Background Homogeneity		
Homogeneous	2, 151, 201	2, 201
Heterogeneous	201	186, 201
Type of Terrain		
Level	143	143, 149, 221, 229, 256
Rolling	143, 201	143, 201, 221, 256
Rough	143	143, 221, 256
Amt. of Vegetation		
Sparse	143, 201	143, 149, 201, 221
Occasional	143, 201	143, 201, 221
Heavy	143, 201	143, 201, 221
Illumination		
Daylight (>100 ft. 1.)	2, 143, 151, 201, 204	2, 12, 37, 143, 149, 155, 178, 188,
Twilight & Night (<1 ft. 1.)	143, 151, 204	36, 99, 143, 204
Cloud Cover	204	204
Visibility		
Clear (20 miles)	2, 142, 143, 151, 201, 204	2, 12, 36, 142, 143, 149, 178, 186,
Lt. Haze (10-19 miles)	2, 142, 143, 201, 204	2, 12, 36, 142, 143, 178, 186, 192,
Low (below 9 miles)	2, 142, 143, 201, 204	2, 12, 36, 142, 143, 192, 201, 204,
Altitude		
Nap of Earth	143	143, 192
Low (100-500)	143, 201, 204	12, 143, 155, 192, 201, 204, 221,
Med (501-5000)	143, 201, 204	12, 36, 143, 155, 178, 186, 192,
High (Above 5000)	2, 142, 143, 151, 204	2, 12, 37, 99, 142, 143, 155, 177,
Speed		
Slow (below 100 mph)	143	143, 186, 188, 229
Med (101-299 mph)	143, 201	143, 186, 188, 201, 226
High (over 300 mph)	143	143, 186, 188, 226, 237
Type of Aircraft		
Light Planes	204	97, 204, 221, 229
Jets		237
Observer Experience		
None		
Training or Experience		
Briefing, Knowledge		
None or Slight		
Thorough		229
Load on Observer		
Heavy	204	204, 226
Light	204	204, 226, 229
Response Required		
Detection	2, 143, 201, 204	2, 97, 99, 143, 148, 149, 155,
Recognition		149, 162, 186, 256
Identification		148, 221, 229
Type of TDI		
Air to Ground	2, 142, 143, 201, 204	2, 36, 142, 143, 148, 149, 155,
Air to Air	151	97, 99, 177, 188, 237
Ground to Air		99, 261
Ground to Ground		
Display & Photos		162

CHARACTERISTICS OF OUTSIDE ENVIRONMENT

Atmospheric Atten/Transmit Meteorological Range
201,204,206,221,226,237,256,261
220,221,229,237,256
206,220,221,229,237,256
221,237,256
192,201,204,206,221,226,229,237,256,261
188,192,201,204,206,221,226,229,237,256
201,204,206,226,229,237,256
206,226,229,237
226,256
201,204,226,229
178,186,192,204,229,237
162,177,178,188,192,196,201,204,206,221,226,229,237,256,261
178,186,192,196,201,204,206,221,226,229,256

III. MODELS AND ANALYTICAL STUDIES

CHARACTERISTICS OF OUTSIDE ENVIRONMENT

	Terrain Types	Type of Vegetation
CONDITIONS		
Type of Target		
Artificial		
Military Object, Mobile	200,201,221,256,261	162,201,221
Other Military Object		162
Contrast		
High (>80%)	200,201,221,256	201,221
Med (20-80%)	200,201,221,256	201,221
Low (<20%)	200,201,221,256	201,221
Camouflage	200	
Target Motion	200	
Target Density		
Low (single)		
High (grouped)		
Background Homogeneity		
Homogeneous	201	201
Heterogeneous	201	201
Type of Terrain		
Level	34,143,200,221,256	143,221
Rolling	34,143,200,201,221,256	143,201,221
Rough	34,143,200,221,256	143,221
Amt. of Vegetation		
Sparse	143,201,221	143,201,221
Occasional	143,201,221	143,201,221
Heavy	143,201,221	143,201,221
Illumination		
Daylight (>100 ft. 1.)	143,200,201,221,256,261,	143,201,221
Twilight & Night (<1 ft. 1.)	143	143
Cloud Cover		
Visibility		
Clear (20 miles)	143,200,201,221,256	143,201,221
Lt. Haze (10-19 miles)	143,201,256	143,201
Low (below 9 miles)	143,201	143,201
Altitude		
Nap of Earth	34,143	143
Low (100-500)	34,143,200,201,205,221,256	143,201,205,221
Med (501-5000)	34,143,201	143,201
High (Above 5000)	143	143
Speed		
Slow (below 100 mph)	143,200	143
Med (101-299 mph)	143,200,201	143,201
High (over 300 mph)	143,200,205	143,205
Type of Aircraft		
Light Planes	200,221	221
Jets	200	
Observer Experience		
None		
Training or Experience		
Briefing, Knowledge		
None or Slight		
Thorough		
Load on Observer		
Heavy		
Light		
Response Required		
Detection	73,95,143,200,201,221,256,261	95,143,162,201,221
Recognition	256	162
Identification	221	221
Type of TDI		
Air to Ground	34,143,201,205,221,256	143,201,205,221
Air to Air		
Ground to Air	200,261	
Ground to Ground		
Display & Photos		162

AIRCRAFT CHARACTERISTICS

Altitude
186,229
40,162,177,178,192,200,201,204,226,254,256
10,40,162
12,155,186,200,201,229,254,256
12,155,186,192,200,201,229,256
12,155,186,200,201,254,256
200
178,192,200
201
186,201
34,143,149,200,229,256
34,143,200,201,256
34,143,200,256
143,149,201
143,201
143,201
12,40,143,149,155,178,192,200,201,204,226,229,254,256
143,204
204
12,142,143,149,178,186,192,200,201,204,226,229,254,256
12,40,142,143,178,186,192,201,204,226,229,256
12,142,143,192,201,204,226,229
12,34,40,143,192
12,20,34,40,143,155,192,200,201,204,226,256
12,34,40,143,155,178,186,192,201,204,226,229,254
10,12,40,142,143,155,177,178,186,192,204,229,254
20,40,143,186,200,229,254
20,40,143,186,200,201,226,254
10,20,40,143,186,200,226,254
200,204,229
10,200
40
229
204,226
40,204,226,229
10,40,73,95,143,148,149,155,162,177,178,181,192,200,201,204,226,229,254,256
10,149,162,186,256
40,148,229
10,20,34,40,142,143,148,149,155,178,181,186,192,201,204,226,229,254,256
177
200
162

AIRCRAFT CHARACTERISTICS

	Range
CONDITIONS	
Type of Target	
Artificial	186, 229
Military Object, Mobile	39, 40, 97, 162, 178, 188, 192, 200, 201, 221, 237, 261
Other Military Object	39, 40, 162
Contrast	
High (>80%)	12, 186, 188, 200, 201, 221, 229, 237
Med (20-80%)	12, 186, 188, 192, 200, 201, 221, 229, 237
Low (<20%)	12, 186, 188, 200, 201, 221, 237
Camouflage	200
Target Motion	178, 188, 192, 200, 237
Target Density	
Low (single)	237
High (grouped)	237
Background Homogeneity	
Homogeneous	201
Heterogeneous	186, 201
Type of Terrain	
Level	143, 200, 221, 229
Rolling	143, 200, 201, 221
Rough	143, 200, 221
Amt. of Vegetation	
Sparse	143, 201, 221
Occasional	143, 201, 221
Heavy	143, 201, 221
Illumination	
Daylight (>100 ft. l.)	12, 40, 143, 178, 188, 192, 200, 201, 221, 229, 237, 261
Twilight & Night (<1 ft. l.)	143
Cloud Cover	
Visibility	
Clear (20 miles)	12, 142, 143, 178, 186, 188, 192, 200, 201, 221, 229, 237
Lt. Haze (10-19 miles)	12, 40, 142, 143, 178, 186, 192, 201, 229, 237
Low (below 9 miles)	12, 142, 143, 192, 201, 229, 237
Altitude	
Nap of Earth	12, 40, 143, 192
Low (100-500)	12, 39, 40, 143, 192, 200, 201, 221
Med (501-5000)	12, 40, 143, 178, 186, 192, 201, 229
High (Above 5000)	12, 40, 142, 143, 178, 186, 192, 229, 237
Speed	
Slow (below 100 mph)	40, 143, 186, 188, 200, 229
Med (101-299 mph)	40, 143, 186, 188, 200, 201
High (over 300 mph)	39, 40, 143, 186, 188, 200, 237
Type of Aircraft	
Light Planes	97, 200, 221, 229
Jets	200, 237
Observer Experience	
None	
Training or Experience	40
Briefing, Knowledge	
None or Slight	
Thorough	229
Load on Observer	
Heavy	
Light	40, 229
Response Required	
Detection	39,40,97,143,148,162,178,188,192,200,201,221,229,237,261
Recognition	39, 162, 186
Identification	40, 148, 221, 229
Type of TDI	
Air to Ground	39, 40, 142, 143, 148, 178, 186, 192, 201, 221, 229
Air to Air	97, 188, 237
Ground to Air	200, 261
Ground to Ground	
Display & Photos	162

AIRCRAFT CHARACTERISTICS

Approach Angle	Speed
	186
40, 151, 162, 178, 201, 237	40, 162, 178, 188, 200, 201, 226, 237, 254, 261
40, 162	40, 162
201, 237	186, 188, 200, 201, 237, 254
201, 237	186, 188, 200, 201, 237
201, 237	186, 188, 200, 201, 237, 254
	200
151, 178, 237	178, 188, 200, 237
237	237
237	237
151, 201	201
201	186, 201
	143, 149, 200
201	143, 200, 201
	143, 200
201	143, 149, 201
201	143, 201
201	143, 201
40, 151, 178, 201, 237	40, 143, 149, 178, 188, 200, 201, 226, 237, 254, 261
151	143
151, 178, 201, 237	143, 149, 178, 186, 188, 200, 201, 226, 237, 254
40, 178, 201, 237	40, 143, 178, 186, 201, 226, 237
201, 237	143, 201, 226, 237
40	40, 143
40, 201	20, 40, 143, 200, 201, 205, 226
40, 178, 201	40, 143, 178, 186, 201, 226, 254
40, 151, 178, 237	40, 143, 178, 186, 237, 254
40	20, 40, 143, 186, 188, 200, 254
40, 201	20, 40, 143, 186, 188, 200, 201, 226, 254
40, 237	20, 40, 143, 186, 188, 200, 205, 226, 237, 254
	200
237	200, 237
40	40
	226
40	40, 226
40, 148, 162, 178, 181, 201, 237	40, 143, 148, 149, 162, 178, 181, 188, 200, 201, 237, 254, 261
162	149, 162, 186, 226
40, 148	40, 148
40, 148, 178, 181, 201	20, 40, 143, 148, 149, 178, 181, 186, 201, 205, 226, 254
151, 237	188, 237
	200, 261
162	162

III. MODELS AND ANALYTICAL STUDIES

CONDITIONS	AIRCRAFT CHARACTERISTICS: Search Pattern	AIRCRAFT CHARACTERISTICS: Wind. Scr. Trans.	OBSERVER CHARACTERISTICS: Visual Skills
Type of Target			
Artificial			
Military Object, Mobile		151	188, 192, 201, 237
Other Military Object			
Contrast			
High (>80%)			188, 201, 237
Med (20-80%)			188, 192, 201, 237
Low (<20%)			188, 201, 237
Camouflage			
Target Motion		151	188, 192, 237
Target Density			
Low (single)			237
High (grouped)			237
Background Homogeneity			
Homogeneous		151	201
Heterogeneous			201
Type of Terrain			
Level	143		
Rolling	143		201
Rough	143		
Amt. of Vegetation			
Sparse	143		201
Occasional	143		201
Heavy	143		201
Illumination			
Daylight (>100 ft. l.)	143	151	188, 192, 201, 237
Twilight & Night (<1 ft. l.)	143	151	
Cloud Cover			
Visibility			
Clear (20 miles)	143	151	188, 192, 201, 237
Lt. Haze (10-19 miles)	143		192, 201, 237
Low (below 9 miles)	143		192, 201, 237
Altitude			
Nap of Earth	143		192
Low (100-500)	143		192, 201
Med (501-5000)	143		192, 201
High (Above 5000)	143	151	192, 237
Speed			
Slow (below 100 mph)	143		188
Med (101-299 mph)	143		188, 201
High (over 300 mph)	143		188, 237
Type of Aircraft			
Light Planes			
Jets			237
Observer Experience			
None			
Training or Experience			
Briefing, Knowledge			
None or Slight			
Thorough			
Load on Observer			
Heavy			
Light			
Response Required			
Detection	143, 181		188, 192, 196, 201, 237
Recognition			
Identification			
Type of TDI			
Air to Ground	143, 181		192, 196, 201
Air to Air		151	188, 237
Ground to Air			
Ground to Ground			
Display & Photos			

TASK CHARACTERISTICS

Knowledge About Expected Target	Task Requirements	Search and Scan Techniques
39	97	40,97,99,162,178,188,192,201,221,228,237,254
39		10,40,162
		155,188,201,221,237,254
		155,188,192,201,221,228,237
		155,188,201,221,228,237,254
		178,188,192,237
		237
		237
		201
		201
		143,221
		143,201,221
		143,221
		143,201,221
		143,201,221
		143,201,221
		40,143,155,178,188,192,201,221,228,237,254
		99,143,228
		143,178,188,192,201,221,237,254
		40,143,178,192,201,237
		143,192,201,237
		40,143,192
39		20,40,143,155,192,201,221
		40,143,155,178,192,201,254
		10,40,99,143,155,178,192,237,254
		20,143,188,254
		20,143,188,201,254
39		10,20,143,188,228,237,254
	97	97,221
		10,237
		40
		40
39	97,148	10,39,40,97,99,143,148,155,162,178,188,192,196,201,221,228,237,254
39		10,39,162
	148	40,148,221
39	148	10,20,39,40,143,148,155,178,192,196,201,221,228,254
	97	97,99,188,228,237
		99
		162

III. MODELS AND ANALYTICAL STUDIES

TASK CHARACTERISTICS

	Size of Field Searched	Miscellaneous, Equipment, No. of Observers	
CONDITIONS			
Type of Target			
Artificial		113	
Military Object, Mobile	39, 178, 201, 226	162, 204	
Other Military Object	39	162	
Contrast			
High (>80%)	201	113	
Med (20-80%)	201	113	
Low (<20%)	201	113	
Camouflage			
Target Motion	178	188	
Target Density			
Low (single)			
High (grouped)			
Background Homogeneity			
Homogeneous	201		
Heterogeneous	201		
Type of Terrain			
Level		143	
Rolling	201	143	
Rough		143	
Amt. of Vegetation			
Sparse	201	143	
Occasional	201	143	
Heavy	201	143	
Illumination			
Daylight (>100 ft. l.)	178, 201, 226	113, 143, 204	
Twilight & Night (<1 ft. l.)		113, 143, 204	
Cloud Cover		204	
Visibility			
Clear (20 miles)	178, 201, 226	143, 204	
Lt. Haze (10-19 miles)	178, 201, 226	143, 204	
Low (below 9 miles)	201, 226	143, 204	
Altitude			
Nap of Earth		143	
Low (100-500)	39, 201, 226	143, 204	
Med (501-5000)	178, 201, 226	143, 204	
High (Above 5000)	178	143, 204	
Speed			
Slow (below 100 mph)	226	143	
Med (101-299 mph)	201, 226	143	
High (over 300 mph)	39	143	
Type of Aircraft			
Light Planes		204	
Jets			
Observer Experience			
None			
Training or Experience			
Briefing, Knowledge			
None or Slight			
Thorough			
Load on Observer			
Heavy	226	204	
Light	226	204	
Response Required			
Detection	148, 178, 201, 226	143, 162, 204	
Recognition		162	
Identification	148		
Type of TDI			
Air to Ground	148, 178, 201, 226	113, 143, 204	
Air to Air			
Ground to Air			
Ground to Ground			
Display & Photos		162	

SECONDARY VARIABLES

Apparent Contrast	Apparent Motion	Apparent Size
186,229		229
97,178,201,221,237	39,178,201,237	97,178,201,206
	10,39	
186,201,221,229,237	201,237	201,206,229
186,201,221,229,237	201,237	201,206,229
186,201,221,237	201,237	201,206
178,237	178,237	178,206
237	237	
237	237	
201	201	201
186,201	201	201
143,221,229	143	143,229
143,201,221	143,201	143,201
143,221	143	143
143,201,221	143,201	143,201
143,201,221	143,201	143,201
143,201,221	143,201	143,201
143,178,201,221,229,237	143,178,201,237	143,178,201,206,229
143	143	143
143,178,186,201,221,229,237	143,178,201,237	143,178,201,206,229
143,178,186,201,229,237	143,178,201,237	143,178,201,206,229
143,201,229,237	143,201,237	143,201,206,229
143	143	143
143,201,205,221	20,39,143,201,205	143,201,205
143,178,186,201,229	143,178,201	143,178,201,229
143,178,186,229,237	10,143,178,237	143,178,229
143,186,229	20,143	143,229
143,186,201	20,143,201	143,201
143,186,205,237	10,20,39,143,205,237	143,205
97,221,229		97,229
237	10,237	
229		229
229		229
97,143,178,201,221,229,237	10,39,143,178,201,237	97,143,178,181,201,206,229
186	10,39	
221,229		229
143,178,186,201,205,221,229	10,39,143,178,201,205	20,143,178,181,201,205,206,229
97,237	237	97

III. MODELS AND ANALYTICAL STUDIES — SECONDARY VARIABLES

	Exposure Time	
CONDITIONS		
Type of Target		
Artificial	186	
Military Object, Mobile	39, 97, 162, 201, 228, 261	
Other Military Object	39, 162	
Contrast		
High (>80%)	186, 201	
Med (20-80%)	186, 201, 228	
Low (<20%)	186, 201, 228	
Camouflage		
Target Motion		
Target Density		
Low (single)		
High (grouped)		
Background Homogeneity		
Homogeneous	201	
Heterogeneous	186, 201	
Type of Terrain		
Level	143	
Rolling	143, 201	
Rough	143	
Amt. of Vegetation		
Sparse	143, 201	
Occasional	143, 201	
Heavy	143, 201	
Illumination		
Daylight (>100 ft. 1.)	143, 201, 228, 261	
Twilight & Night (<1 ft. 1.)	143, 228	
Cloud Cover		
Visibility		
Clear (20 miles)	143, 186, 201	
Lt. Haze (10-19 miles)	143, 186, 201	
Low (below 9 miles)	143, 201	
Altitude		
Nap of Earth	143	
Low (100-500)	20, 39, 143, 201, 205	
Med (501-5000)	143, 186, 201	
High (Above 5000)	143, 186	
Speed		
Slow (below 100 mph)	20, 143, 186	
Med (101-299 mph)	20, 143, 186, 201	
High (over 300 mph)	20, 39, 143, 186, 205, 228	
Type of Aircraft		
Light Planes	97	
Jets		
Observer Experience		
None		
Training or Experience		
Briefing, Knowledge		
None or Slight		
Thorough		
Load on Observer		
Heavy		
Light		
Response Required		
Detection	39, 97, 143, 162, 201, 228, 261	
Recognition	39, 162, 186	
Identification		
Type of TDI		
Air to Ground	20, 39, 143, 186, 201, 205, 228	
Air to Air	97, 228	
Ground to Air	261	
Ground to Ground		
Display & Photos	162	

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APPENDIX B

Target Detection/Identification Model Calculations

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APPENDIX B

Target Detection/Identification Model Calculations

Overview

The preliminary target detection/identification (TDI) model developed here is applicable to the problem of air-to-ground visual detection and identification of tactical targets. With estimates of eight input variables, the user can obtain the probability of identifying a target as a function of slant range from the observer to the target.

The model uses the following input variables:

1. Target size.
2. Target shape.
3. Target/ground brightness contrast.
4. Clutter.
5. Slant range.
6. Aircraft altitude.
7. Aircraft speed.
8. Terrain type (smooth, rolling, rough).

The model is based on the Whittenburg, et al., (1959a) field data. It incorporates a modification of one of the National Defense Research Committee (1946) detection threshold nomographs and Erickson's data on line-of-sight probabilities.

The preliminary model was obtained by (1) grouping the input variables into three composite variables--target apparent size, distinctiveness, and effective exposure time, (2) obtaining measures on each composite for the targets in the Whittenburg study, and (3) selecting the combination of the three composites which, when applied to the Whittenburg data, resulted in the "best" prediction of actual detection/identification probabilities. As the model now stands, $P_{TDI} = \sqrt{S}\, CT_e$; that is, probability of detection/identification is a direct function of $\sqrt{S}$--the square root of target average square mil size (ranging from 5-100); C--distinctiveness value (ranging from 1-12); and T_e--effective exposure time (ranging from 01 to 1.00). A minimum exposure time of 5 seconds is assumed to be necessary for TDI, and all times greater than 5 seconds are assumed to be equal to 1.00.

This Appendix describes (1) the calculations that were carried out on the Whittenburg data, and (2) steps to be used in calculating model values for predicting probabilities of detection/identification for expected targets.

Data Calculations

The following is a discussion of the steps which were carried out in calculating values of the composite variables for the targets from the Whittenburg study. A summary of the data is presented in Table B-1, and a summary of the definitions of all symbols used in the calculations is presented in Table B-2.

1. The following information on the 46 Whittenburg targets was given:

    a. Probabilities of detection, identification, and detection/identification.

    b. Scan pattern--Figure B-1 shows the approximate ground area searched from the plane. Figure B-2 shows a close-up of the ground area searched. Observers used a standard side-scan pattern, covering the area from 45° from line-of-flight to 135° from line-of-flight, scanning out toward the horizon and inward toward the aircraft. At the point closest to the aircraft, the scanned area was approximately 200 feet wide.

    c. Terrain type--rolling.

    d. Altitude of the aircraft, H, was 200 ft.

    e. Speed of the aircraft, V, was 100 m. p. h.

    f. Target size, A. Projected areas for each of the targets were estimated in the Whittenburg study. These estimates were used as input data for the preliminary model. They are given in Table B-1. (The target size estimates include the personnel located at the targets.)

    g. Closest slant range, R_o, (the slant range when the angle between the target and line-of-flight was 90°) was given for each target (see Table B-1).

2. In order to determine the time each target was in view, and to find its average apparent size, it was necessary to determine the dimensions of the ground area scanned and the target position.

    a. Closest ground range from the line-of-flight to the target, D_o, was calculated by the formula: $D_o = \sqrt{R_o^2 - H^2}$.

TABLE B-1

CALCULATIONS AND MODEL VALUES FOR WHITTENBURG STUDY TARGETS

Target			Slant Ground Ranges (feet)							Target sq. mil size			Target Distinctiveness	Effective Exposure Time						Effective Size	Probability		
No.	Description	Area (yds)	R_o	D_o	R_I	D_I	M	D_M	R_M	S_1	S_2	$\sqrt{S}$	C	T_o	T_s	P_o	P_M	$\bar{P}$	T_e	$\sqrt{S}CT_e$	P_{TDI}	P_D	P_I
1	Jeep	7.36	430	380.7	3600	3594	2541	613.2	645.0	358	159	16.06	9	6.55	1	.99	.97	.98	.980	142	.97	.98	.95
3	Personnel	.81	230	113.6	1320	1305	923	241.9	313.9	138	74	10.30	4.5	2.91	.76	1.00	.99	.995	.756	35	.38	.55	.02
4	2 1/2 t T	20.20	670	639.5	5250	5246	3709	977.7	997.9	405	183	17.15	9	10.08	1.	.97	.94	.955	.955	147	.88	.90	.76
5	81 mm.	1.18	450	403.1	1530	1517	1073	644.7	675.0	52	23	6.16	9	6.86	1.	.98	.95	.965	.965	53	.82	.90	.57
6_1	2 1/2 t T	20.20	860	836.4	5250	5246	3709	1255.6	1271.3	246	113	13.42	9	12.77	1.	.95	.91	.93	.930	112	.92	.95	.79
6_2	Jeep	6.50	860	836.4	3430	3424	2421	1255.6	1271.3	79	36	7.62	12	12.77	1.	.95	.91	.93	.930	85	.98	100	.90
6_3	3/4 t T	12.13	860	836.4	4500	4496	3179	1255.6	1271.3	148	68	10.39	6	12.77	1.	.95	.91	.93	.930	58	.74	.79	.55
7_1	50 C_d MG	1.33	350	287.2	1590	1577	1115	482.1	521.9	98	44	8.43	3	5.28	1.	.99	.98	.985	.985	25	.11	.14	.02
7_2	30C	.95	350	287.2	1375	1360	962	482.1	521.9	70	31	7.07	4	5.28	1.	.99	.98	.985	.985	28	.14	.14	.12
7_3	106	1.98	350	287.2	1890	1879	1329	482.1	521.9	145	65	10.25	4	5.28	1.	.99	.98	.985	.985	40	.34	.36	.31
8	81 mm.	1.18	640	607.9	1530	1517	1073	933.1	954.3	26	12	4.36	4.5	9.65	1.	.97	.94	.955	.955	19	.42	.60	.00
9_1	5 DC	1.33	260	166.1	1590	1577	1115	313.7	372.0	177	87	11.49	3	3.63	.85	1.00	.99	.995	.846	29	.33	.36	.24
9_2	30 C	.95	260	166.1	1375	1360	962	313.7	372.0	126	62	9.70	3	3.63	.85	1.00	.99	.995	.846	25	.30	.31	.24
9_3	106 RR	2.74	260	166.1	2200	2191	1549	313.7	372.0	365	178	16.49	3	3.63	.85	1.00	.99	.995	.846	42	.50	.62	.45
10_1	Jeep	6.92	280	196.0	3520	3514	2484	355.0	407.5	794	375	24.17	4	4.04	.90	.99	.99	.99	.890	86	.80	.93	.31
10_2	30 C	.95	280	196.0	1375	1360	962	355.0	407.5	109	51	8.94	4	4.04	.90	.99	.99	.99	.890	32	.19	.24	.07
11_1	50 C	1.33	250	150.0	1590	1577	1115	291.5	353.6	192	96	12.00	4	3.41	.82	1.00	.99	.995	.816	39	.50	.57	.45
11_2	30 C	.95	250	150.0	1375	1360	962	291.5	353.6	137	68	10.10	4	3.41	.82	1.00	.99	.995	.816	33	.55	.64	.43
11_3	35 RL	1.14	250	150.0	1450	1436	1015	291.5	353.0	164	82	11.09	4	3.41	.82	1.00	.99	.995	.816	36	.58	.64	.48
12	30 C	.95	550	512.3	1375	1360	962	798.3	823.0	28	13	4.47	6	8.35	1.	.98	.95	.965	.965	26	.46	.71	.00
13	30 Cal	.95	230	113.6	1375	1360	962	241.9	313.9	162	87	11.14	4.5	2.91	.76	1.00	.99	.995	.756	38	.74	.86	.29
14_1	Tank	29.81	390	334.8	6000	5997	4241	548.8	584.1	1764	786	35.71	12	5.93	1.	.99	.97	.98	.980	420	.99	100	.93

TABLE B-1
(continued)

Target			Slant Ground Ranges (feet)							Target sq. mil size			Target Distinctiveness	Effective Exposure Time						Effective Size	Probability		
No.	Description	Area (yds)	R_o	D_o	R_I	D_I	M	D_M	R_M	S_1	S_2	$\sqrt{S}$	C	T_o	T_s	P_o	P_M	$\bar{P}$	T_e	$\sqrt{S}CT_e$	P_{TDI}	P_D	P_I
14_2	Jeep & 30	7.41	390	334.8	3620	3614	2553	548.8	584.1	438	195	17.78	6	5.93	1.	.99	.97	.98	.980	105	.80	.98	.12
15_1	50 C	.90	590	555.1	1360	1345	951	858.7	881.6	23	10	4.00	3	8.93	1.	.97	.95	.96	.960	12	.14	.29	.02
15_2	30 C	.52	590	555.1	1020	1000	707	858.7	881.6	13	6	3.16	1.5	8.93	1.	.97	.95	.96	.960	5	.08	.21	.02
16_1	Tank	29.81	450	403.1	6000	5997	4241	644.7	675.0	1325	589	30.94	12	6.86	1.	.98	.96	.97	.970	360	.99	100	.88
16_2	Jeep & 106	7.50	450	403.1	3650	3645	2577	644.7	675.0	333	148	15.49	9	6.86	1.	.98	.96	.97	.970	135	.92	.95	.79
17_1	106	1.98	250	150.0	1890	1879	1329	291.5	353.6	285	143	14.63	4	3.41	.82	1.00	.99	.995	.816	48	.70	.71	.62
17_2	3.5	1.14	250	150.0	1450	1436	1015	291.5	353.6	164	82	11.09	3	3.41	.82	1.00	.99	.995	.816	27	.29	.36	.14
18_1	Tank	29.81	390	334.8	6000	5997	4241	548.8	584.1	1764	786	35.71	11	5.93	1.	.99	.97	.98	.980	385	.97	.98	.88
18_2	50 C	1.33	390	334.8	1590	1577	1115	548.8	584.1	79	35	7.55	4	5.93	1.	.99	.97	.98	.980	30	.37	.50	.07
20	4.2 mortars	2.49	610	576.3	2100	2090	1478	888.5	910.8	60	27	6.63	6	9.22	1.	.97	.95	.96	.960	38	.72	.88	.21
21_1	Sp 155	19.88	990	969.6	5220	5216	3688	1443.7	1457.4	182	84	11.53	12	14.59	1.	.94	.88	.91	.910	126	.89	100	.24
21_2	Towed 155	8.40	990	969.6	3840	3835	2712	1443.7	1457.4	77	36	7.48	9	14.59	1.	.94	.88	.91	.910	61	.74	.86	.12
22	Towed 105	3.79	800	774.6	2700	2693	1904	1168.3	1185.3	53	24	6.16	9	11.93	1.	.96	.92	.94	.940	52	.78	.86	.38
23_1	3/4 truck	12.13	480	436.3	4500	4496	3179	691.4	719.7	473	211	18.49	9	7.31	1.	.98	.96	.97	.970	161	.90	.90	.83
23_2	Jeep	6.50	480	436.3	3430	3424	2421	691.4	719.7	254	113	13.56	5	7.31	1.	.98	.96	.97	.970	66	.62	.64	.45
23_3	Tank (c)	29.81	480	436.3	6000	5997	4241	691.4	719.7	1164	518	29.00	3	7.31	1.	.98	.96	.97	.970	84	.40	.45	.36
23_4	106 RR	1.98	480	436.3	1890	1879	1329	691.4	719.7	77	34	7.48	3	7.31	1.	.98	.96	.97	.970	22	.17	.17	.17
23_5	30 Cal	.95	480	436.3	1375	1360	962	691.4	719.7	37	17	5.20	4	7.31	1.	.98	.96	.97	.970	20	.09	.10	.05
24	50 Cal	1.33	360	299.3	1590	1577	1115	499.0	537.6	92	41	8.12	4	5.44	1.	.99	.98	.985	.985	32	.68	.71	.40
25	Jeep	7.41	560	523.1	3620	3614	2555	813.6	837.8	213	95	12.41	12	8.50	1.	.98	.95	.965	.965	144	.91	.95	.62
26_1	Tank	29.81	360	299.3	6000	5997	4241	499.0	537.6	2070	928	38.72	12	5.44	1.	.99	.98	.985	.985	458	.99	100	.93
26_2	106	2.36	360	299.3	2050	2040	1443	499.0	537.6	164	73	10.86	6	5.44	1.	.99	.98	.985	.985	64	.79	.81	.69
27_1	106	1.98	410	357.9	1890	1879	1329	581.2	614.6	106	47	8.72	6	6.24	1.	.99	.97	.98	.980	51	.89	.90	.83
27_2	50C	1.33	410	357.9	1590	1577	1115	581.2	614.6	71	32	7.21	6	6.24	1.	.99	.97	.98	.980	42	.74	.79	.43

TABLE B-2

Definitions of Symbols Used in Calculating Model Values

H	Aircraft altitude (Input variable).
V	Aircraft velocity (Input variable).
A	Target area in square yards (Input variable).
R_o	Closest slant range from flight path to target (Input variable).
D_o	Closest ground range from the line of flight to the target, $=\sqrt{R_o^2 - H^2}$.
R_I	Threshold identification slant range (Read from Figure B-3).
D_I	Ground range corresponding to the threshold slant range, $=\sqrt{R_I^2 - H^2}$.
M	Ground range at which exposure time is maximum, $=\frac{D_I}{\sqrt{2}}$.
D_M	Maximum ground range at which a target in position D_o can be identified (the distance at which the target first comes into view with this scan pattern), $= D_I$, when $D_o > M$; or, $=\sqrt{D_o^2 + (D_o + 100)^2}$, when $D_o \leq M$.
R_M	Maximum slant range at which the target first comes into view, $=\sqrt{D_M^2 + H^2}$.
$\sqrt{S}$	Square root of average target apparent size, $=\sqrt{\frac{S_1 + S_2}{2}}$.
S_1	Maximum square mil size (apparent target size at closest slant range, R_o), $= A\left(\frac{3000}{R_o}\right)^2$.
S_2	Minimum square mil size (apparent target size at farthest slant range, R_M), $= A\left(\frac{3000}{R_M}\right)^2$.
C	Target distinctiveness (Scaled from photos).
T_e	Effective exposure time, $= T_s\bar{P}$.
T_o	Total possible target exposure time, $=\frac{2\sqrt{D_I^2 - D_o^2}}{V}$, when $D_o > M$; or, $=\frac{2(D_o + 100)}{V}$, when $D_o \leq M$.
T_s	Effective time score, $= 1$, when $T_o \geq 5$ sec.; or, $=\sqrt{T_o/5}$, when $T_o < 5$ sec.

TABLE B-2
(continued)

$\bar{P}$	Average probability of a line of sight from the aircraft along the target path, $= \frac{P_o + P_M}{2}$
P_o	Probability of a line of sight from the aircraft to D_o (Read from Figures B-4 – B-6).
P_M	Probability of a line of sight from the aircraft to D_M (Read from Figures B-4 – B-6).
S_e	Effective target size exposed, $= \sqrt{\bar{S}}\, CT_e$.
P_{TDI}	Probability of target detection/identification (Read from Figure B-7).

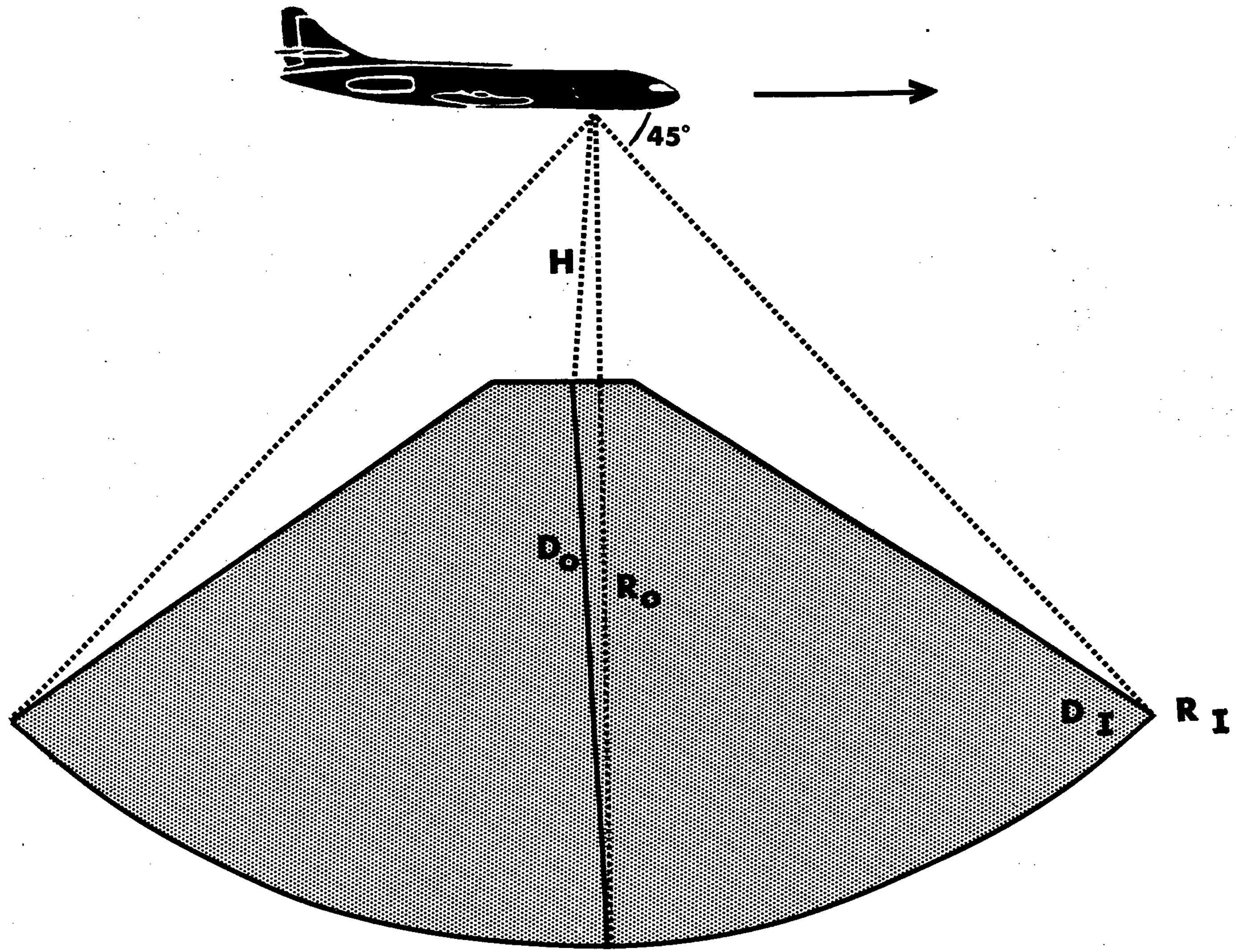

Figure B-1. Ground area scanned in the Whittenburg study. The 45° angle is not a depression angle. It represents the horizontal angle from the line-of-flight to the scanned area.

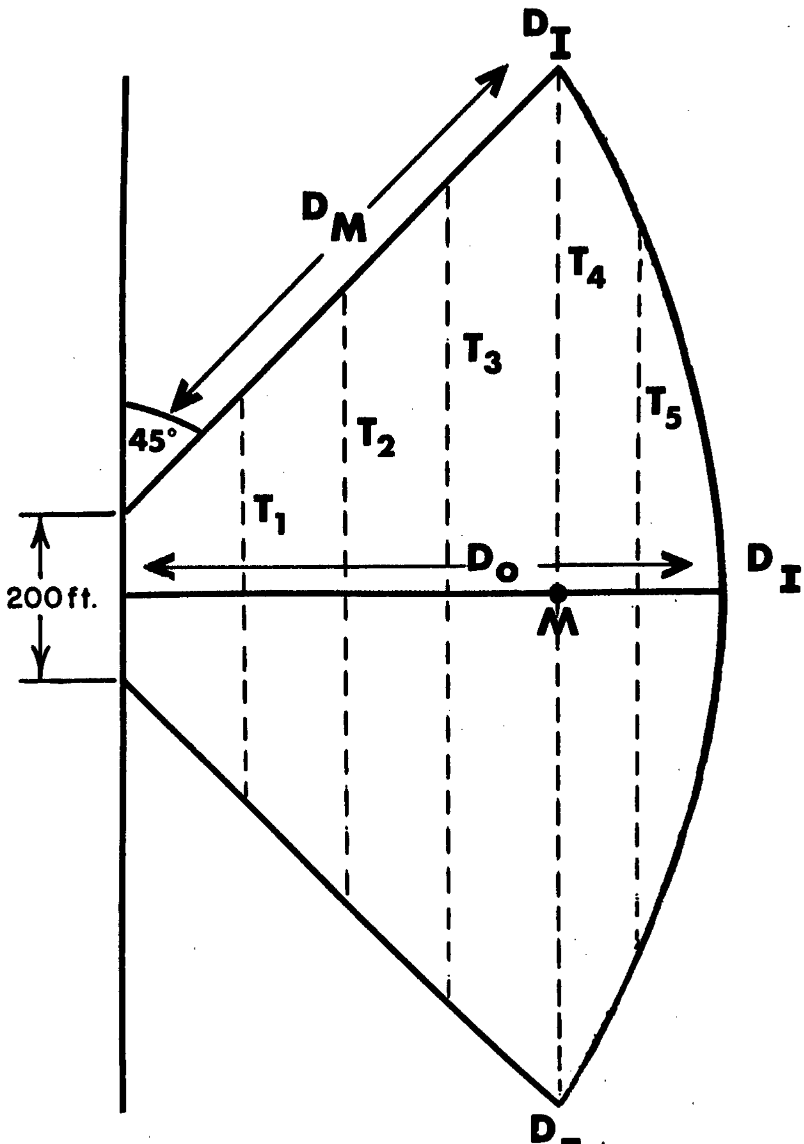

Figure B-2. Ground area scanned.

b. The threshold identification slant range, R_I, (that slant range at which the probability of identification of the target is near zero) was determined for each target by modifying one of the National Defense Research Committee nomographs. The nomographs show threshold detection range as a function of target size, target shape, target/ground brightness contrast, meteorological range, sky/ground ratio, and illumination level. The conditions of the Whittenburg study (target shape--4:1 rectangle; contrast--.5; meteorological range--14 miles; sky/ground ratio--5; and illumination level--100 ft. lamberts) were used as a set of "average operational conditions." Using the nomograph for 4:1 targets at 100 ft. l. illumination, threshold detection range for each target could be determined. However, the nomographs were constructed from laboratory data on target detection thresholds, and a correction was necessary to obtain thresholds which corresponded to actual field detection/identification of targets. Several investigators have suggested that if the contrast value is divided by some factor before entering the nomograph, more realistic detection ranges will be obtained. For example, Gordon (1963) noted that it has been suggested that detection thresholds corresponding to a situation where O does not know where to look for the target can be obtained by dividing the value of actual target/ground contrast by 4.8 before entering the nomograph. In an earlier study (Whittenburg, et al., 1959b) of identification of real and dummy targets, it was found that the threshold size for identification was approximately 5 sq. mils when the observer knew where to look for the target. To obtain threshold ranges from the nomographs which approximated the ranges at which targets would be 5 sq. mils in size, the average contrast value of the Whittenburg study targets--.5--was divided by 12.63. This figure was obtained by plotting on the 4:1, 100 ft. l. nomograph the 5 sq. mil range and size of each of the targets from the study, then working backward to determine the appropriate divisor for contrast. In Figure B-3 the resulting threshold identification ranges are plotted as a function of projected target area in square

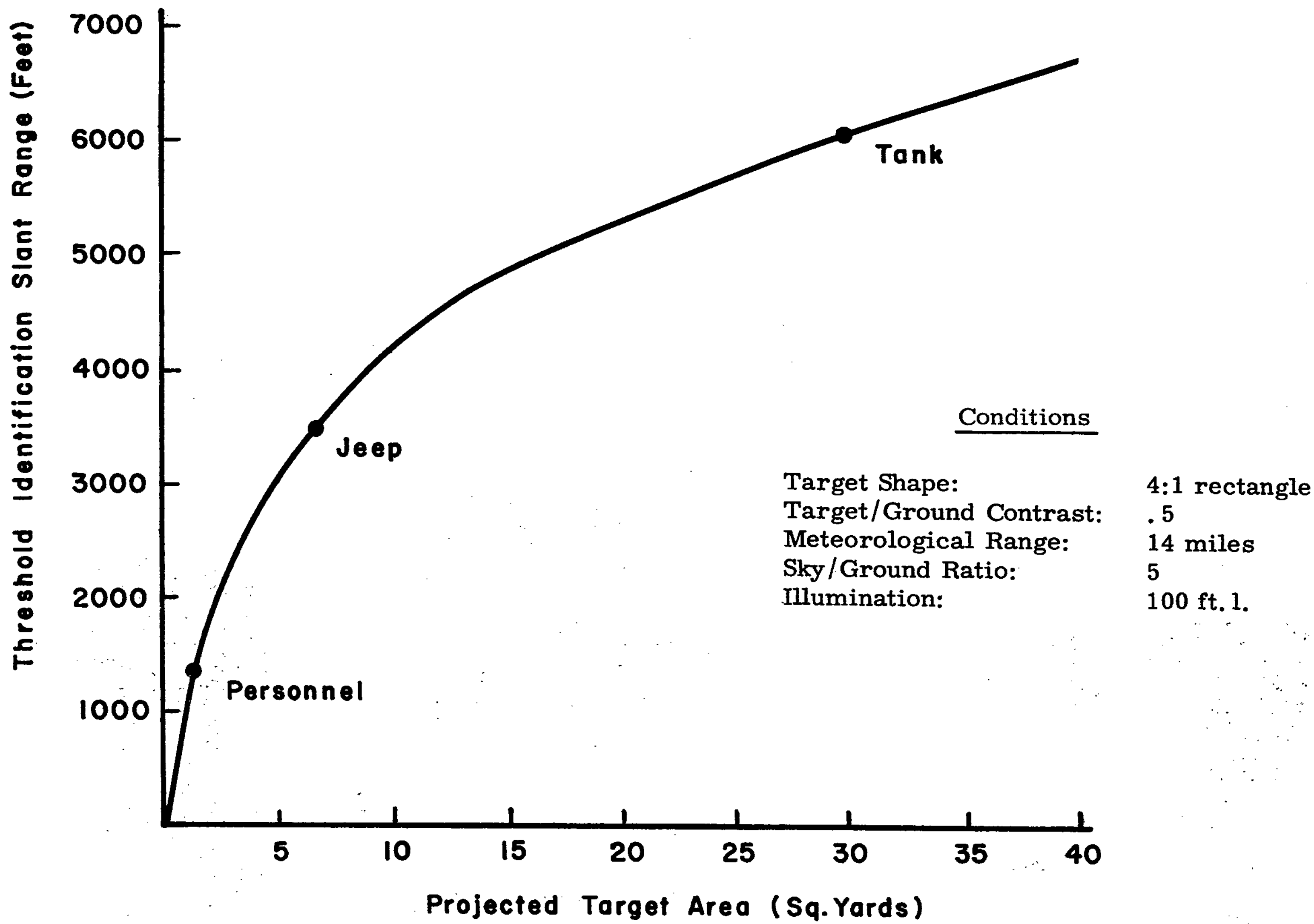

Figure B-3. Threshold identification slant range as a function of target area for "average operational conditions." This curve was constructed from a National Defense Research Committee (1946) nomograph.

yards. The use of the modification of the nomograph for approximating threshold range actually means that instead of a 5 sq. mil threshold size for all targets, small targets may be seen when they are slightly smaller than 5 sq. mils, and large targets must be slightly larger than 5 sq. mils to be seen at extremely long ranges (because of attenuation).

c. The ground range corresponding to the threshold slant range, D_I, was calculated by the formula $D_I = \sqrt{R_I^2 - H^2}$.

d. That ground range at which exposure time is maximum, M, was calculated by the formula $M = \frac{D_I}{\sqrt{2}}$. (This gives only an approximate value.)

e. The maximum ground range at which a target at position D_o can be identified, D_M (the distance at which the target first comes into view with this scan pattern), was calculated as follows: when $D_o > M$, $D_M = D_I$; when $D_o \leq M$, $D_M = \sqrt{D_o^2 + (D_o + 100)^2}$. Note: the "100" reflects the fact that the scanned area was 200 ft. wide at the point closest to the aircraft. (See Figure B-2).

f. The maximum slant range at which the target would come into view, R_M, was determined by the formula: $R_M = \sqrt{D_M^2 + H^2}$.

3. Square root of average target apparent size, $\sqrt{\bar{S}}$, was calculated as follows:

a. Maximum square mil size, S_1 (the apparent size of the target at the closest slant range) was calculated by the formula: $S_1 = A\left(\frac{3000}{R_o}\right)^2$.

b. Minimum square mil size, S_2 (the apparent size of the target at the farthest slant range) was calculated by the formula: $S_2 = A\left(\frac{3000}{R_M}\right)^2$.

c. $\sqrt{\bar{S}} = \sqrt{\frac{S_1 + S_2}{2}}$.

4. Target distinctiveness, C, was determined for the targets in the Whittenburg study by a rough scaling of pictures of each target. Pictures were compared, and a value ranging

from 1 to 12 (low to high distinctiveness) was assigned to each target. In comparing the pictures, it appeared that the targets that "stood out" from their backgrounds (high distinctiveness) were those with relatively high target/ground brightness contrast, those located in the open (high shape contrast), and those which were placed in series or patterns. The targets low in distinctiveness were low contrast objects, located in shadow in cluttered areas.

5. Effective exposure time, T_e, was calculated for each target in the following steps:

   a. Total possible exposure time, T_o, was calculated by the following formulas: when $D_o > M$, $T_o = \frac{2\sqrt{D_I^2 - D_o^2}}{V}$;

      when $D_o \leq M$, $T_o = \frac{2(D_o + 100)}{V}$.

   b. Effective time score, T_s, was calculated as follows: when $T_o \geq 5$ seconds, $T_s = 1$; when $T_o < 5$ seconds, $T_s = \sqrt{T_o/5}$.

   c. Average probability of a line-of-sight from the aircraft along the target path, $\bar{P}$, was determined from smoothed graphs from a study of terrain masking (Erickson, 1961). The graphs are shown in Figures B-4, B-5, and B-6. $\bar{P}$ was obtained as follows: P_o, probability of a line-of-sight from the aircraft to D_o, was read from Figure B-5 (rolling terrain), for the 200-ft. altitude. P_M, probability of a line-of-sight from the aircraft to D_M, was read from Figure B-5. $\bar{P}$ was calculated by averaging the two probabilities: $\bar{P} = \frac{P_o + P_M}{2}$.

   d. Effective exposure time, T_e, was calculated as follows: $T_e = T_s\bar{P}$.

6. Effective target size exposed, S_e, was calculated as follows: $S_e = \sqrt{S}\,CT_e$.

7. The function relating probability of detection/identification, P_{TDI}, to effective size exposed was determined by plotting

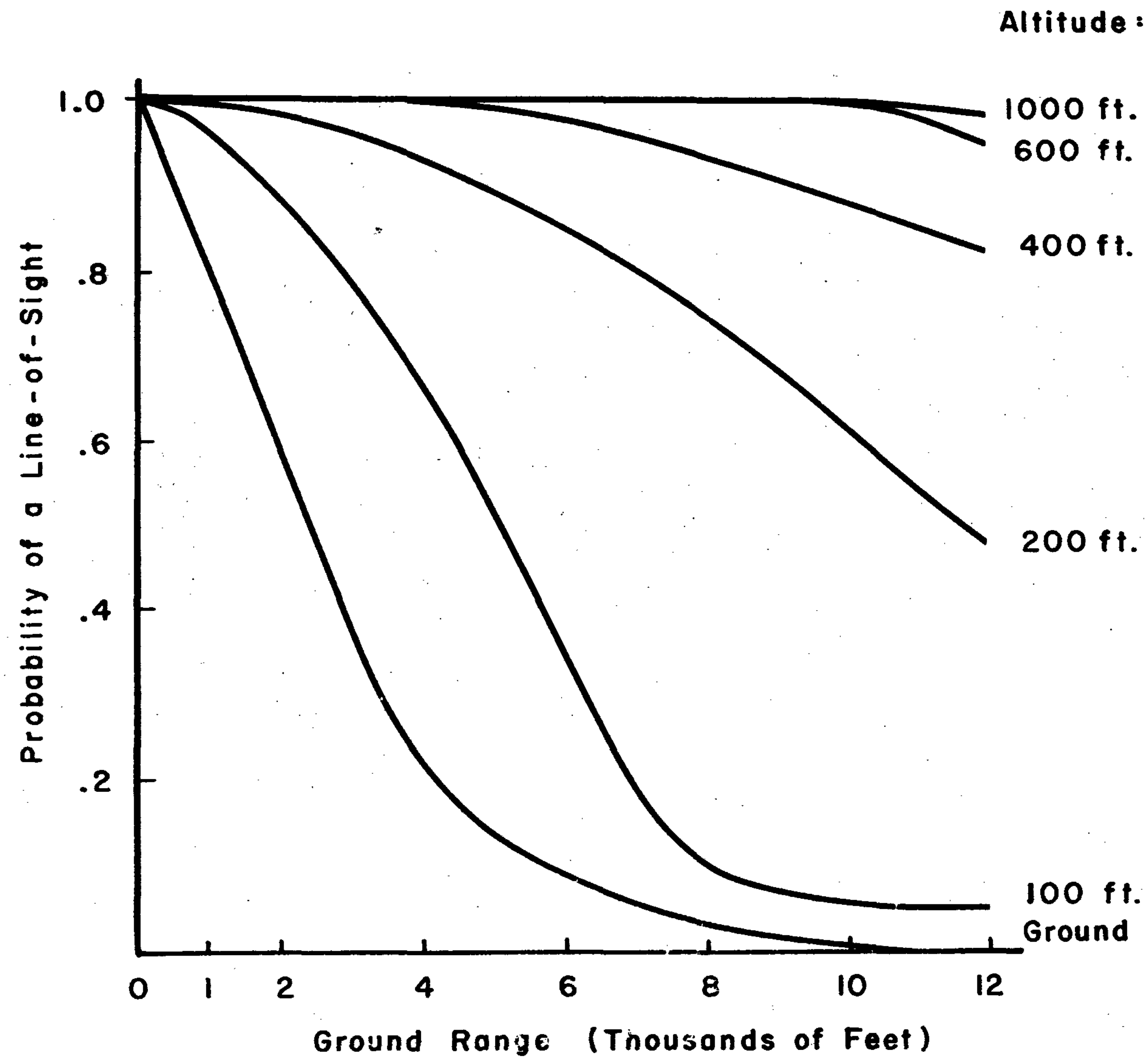

Figure B-4. Probability that there is a line-of-sight to the ground range as a function of altitude. Smooth terrain. (From Erickson, 1961).

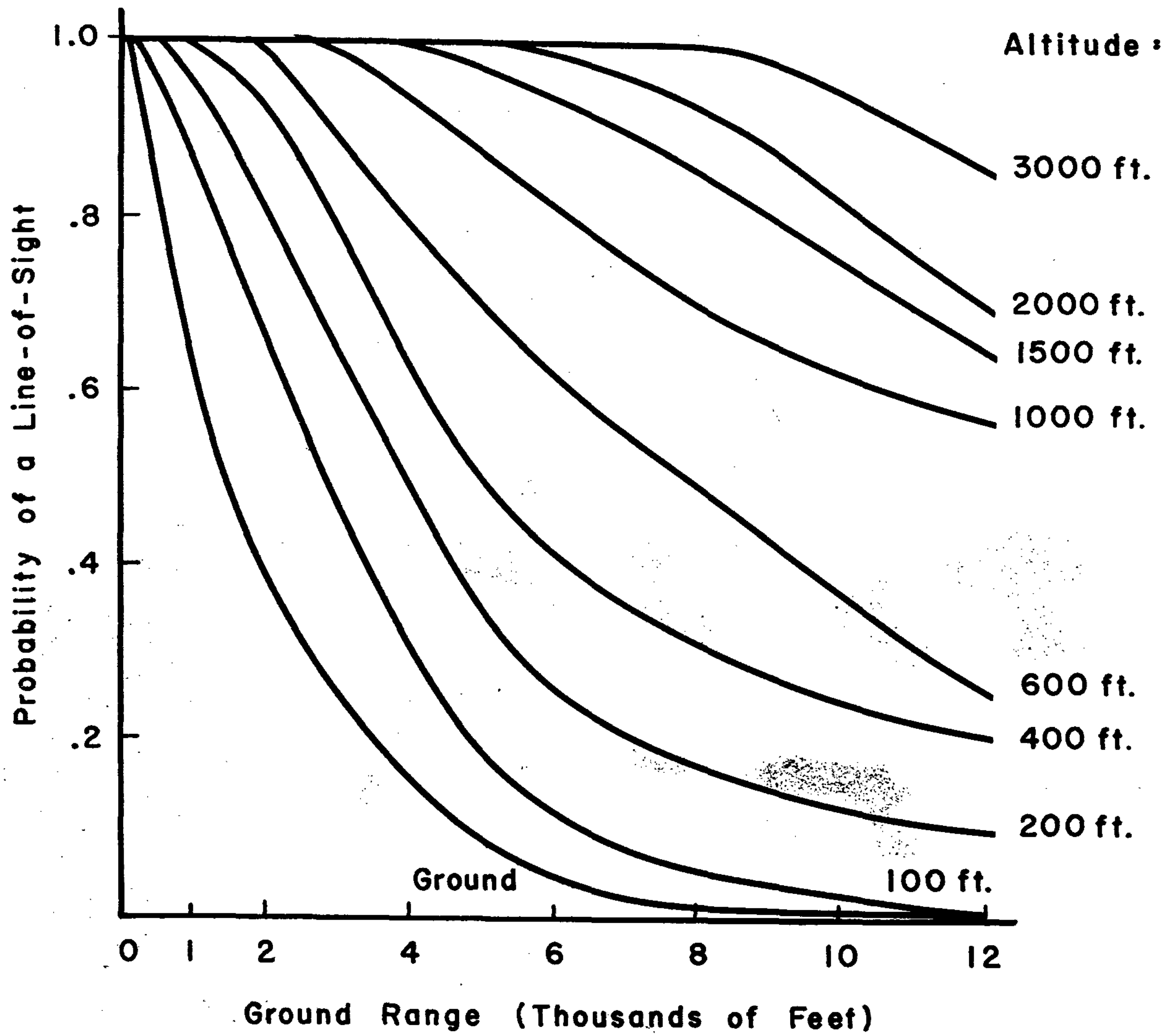

Figure B-25. Probability that there is a line-of-sight to the ground range as a function of altitude. Rolling terrain. (From Erickson, 1961).

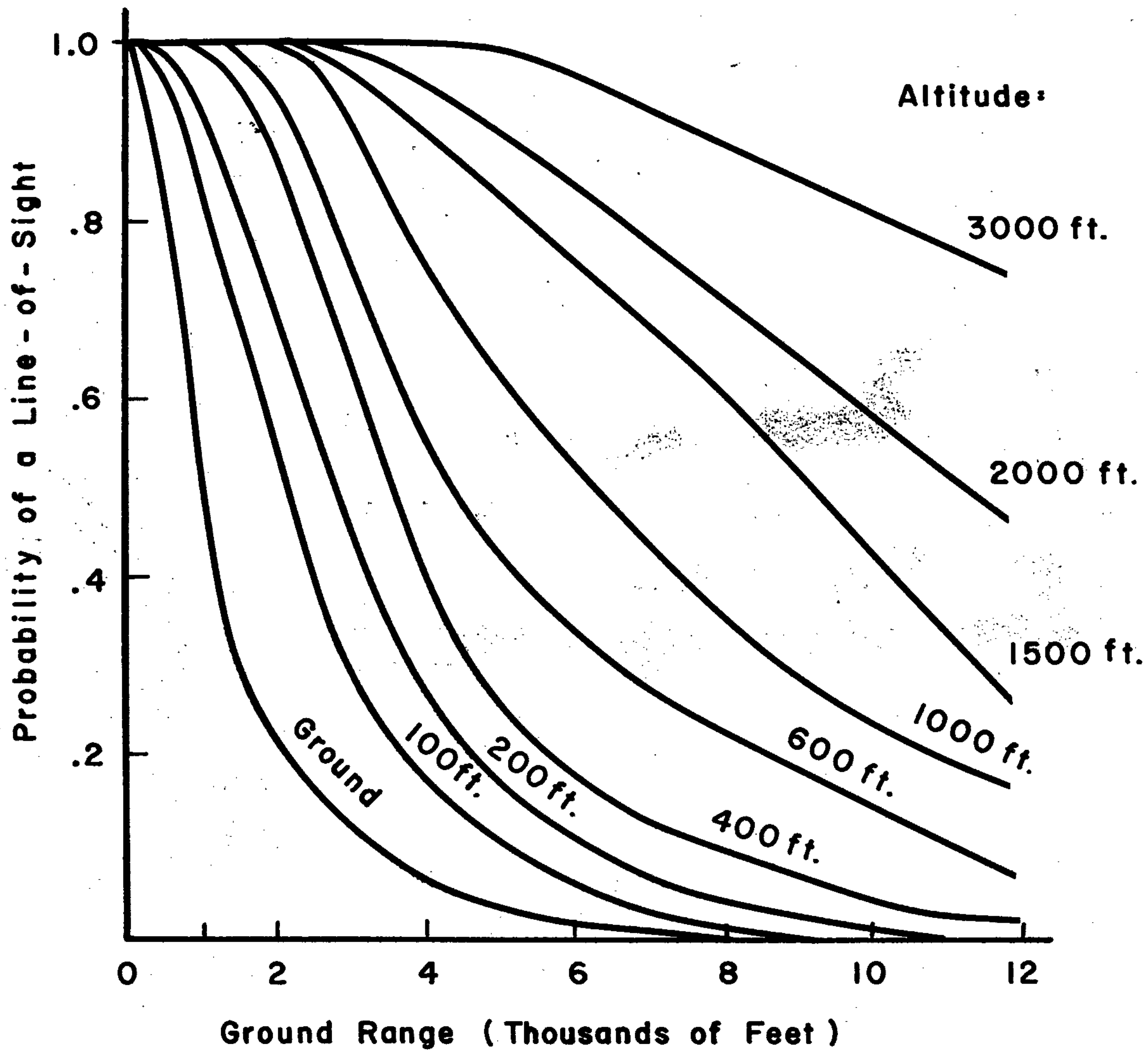

Figure B-6. Probability that there is a line-of-sight to the ground range as a function of altitude. Rough terrain. (From Erickson, 1961).

the data and fitting the best-fitting curve shown in Figure B-7. The resulting formula was: $P_{TDI} = 1 - e^{-.0167 S_e}$.

Use of the Model for Prediction

The preliminary model may be used to predict the probability of detection/identification of tactical targets as a function of slant range from the observer to the target. The model predictions should be realistic for conditions which correspond to those of the Whittenburg study; i.e., daylight, clear visibility, inexperienced observers, side scan pattern, low altitude (100-500 ft.) and slow speed (hover-150 m.p.h.).

Input Variables

To use the model, values for the input variables of target size, distinctiveness, aircraft altitude, aircraft speed, and terrain type must be obtained.

Target Size. The projected areas of a number of tactical targets were estimated in the Whittenburg (1959a) study. These estimates are shown in Table B-3. The following quote explains the basis and procedure by which the projected targed areas were estimated:

> ". . . What is meant [by projected area of a target] is the area of the outline on a plane of all lines which can be constructed from points of the target to the plane, the construction lines all being perpendicular to the plane. An example of projected area is the area of the shadow of an object cast on a flat surface provided:
>
> 1. the light source is far enough away so that its rays are essentially parallel
>
> 2. the surface is perpendicular to the light rays.
>
> The angle between a closed plane surface of area $\overline{A}$ and a plane on which it is to be projected is defined as the angle between their normals. If we call this angle Θ, then the projected area is given by: $A = \overline{A} \cos \Theta$. Consider next a simple solid such as a rectangular prism and a line running to it from some distance away representing the direction from which it is to be viewed. As the prism is projected onto a plane perpendicular to the direction from which it is to be viewed, it can be seen that the projected area will comprise at most 3 of the 6 faces of the prism, one from each pair. Denoting the top area as A_{pl}, the end area by A_{pr}, and the side area by A_{el}, and the total projected area of the solid by A, and the angles between the respective normals to the faces and the line of view by
>
> Θ_{pl}, Θ_{pr}, and Θ_{el}, then A can be represented by:
>
> $$A = A_{pl} \cos \Theta_{pl} + A_{pr} \cos \Theta_{pr} + A_{el} \cos \Theta_{el}$$

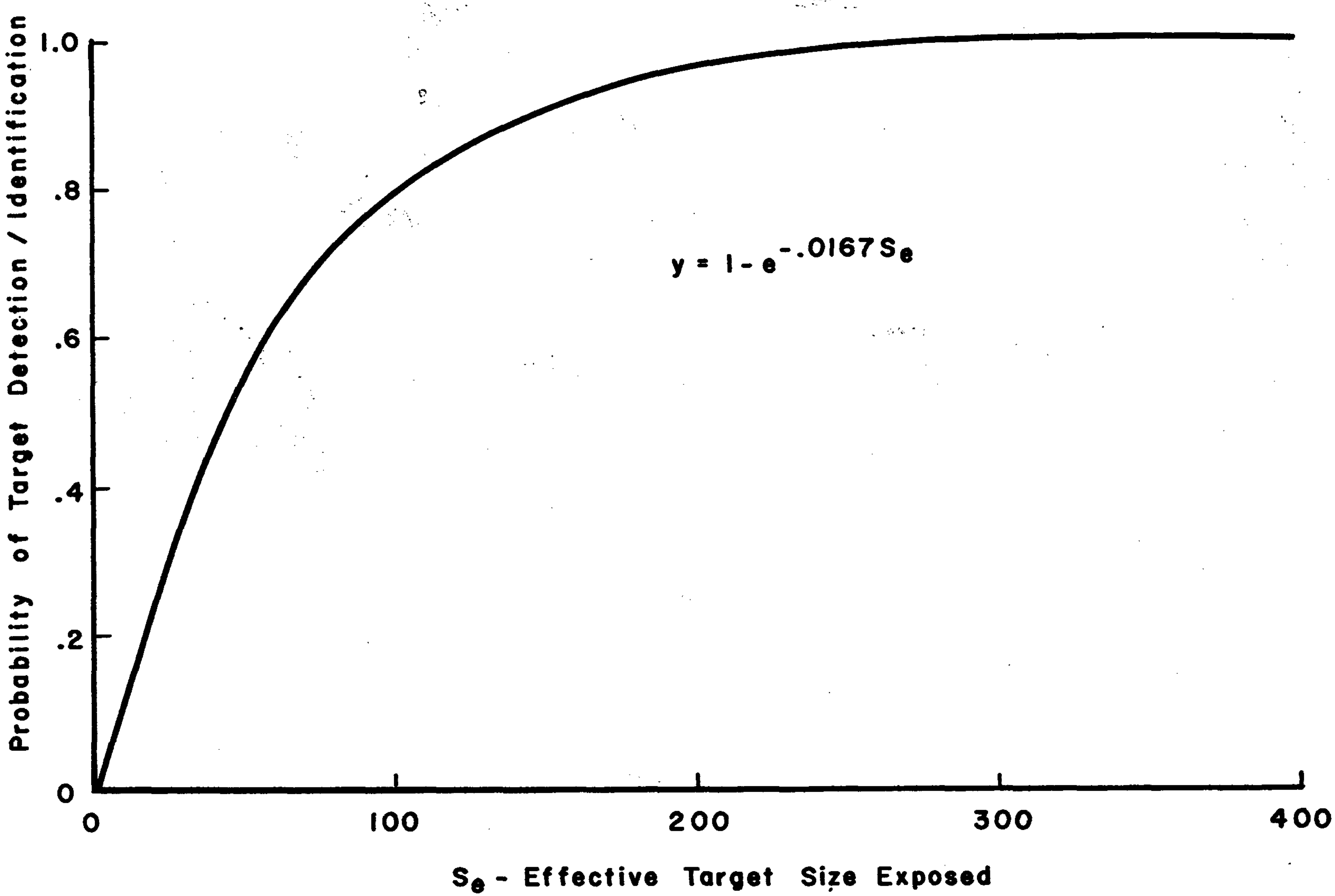

Fig. B-7. Probability of target detection/identification as a function of effective target size exposed. This figure is based on data from Whittenburg, et al. (1959a).

TABLE B-3

PROJECTED AREAS OF TACTICAL TARGETS (SQUARE YARDS)

TARGET	ELEVATION	PLAN	PROFILE	A[1]
Personnel	.33	.08	1.00	.81
105 Howitzer	.97	2.2	3.40	3.79
M-48 Tank	14.04	29.42	8.20	29.81
2 1/2-ton Truck	11.90	18.15	4.96	20.20
30 cal. LMG	.08	.06	.01	.09
1/4-ton Jeep	3.70	5.19	2.37	6.50
H-13	6.75	6.84	2.96	9.55
81mm Mortar	.13	.36	.07	.32
4.2" Mortar	.19	1.12	.19	.87
106 Recoilless Rifle	.66	.60	.067	.77
3/4-ton Truck	8.24	9.71	3.067	12.13
80mm Mortar	.11	.20	.08	.23
155 Howitzer	4.49	4.95	5.11	8.40
106 Recoilless Rifle (ground)	.86	.84	.24	1.12
50 cal. MG	.28	.33	.20	.47
Radio	.06	.19	.03	.16
155 SP	8.70	20.00	5.76	19.88
3.5 RL	.22	.23	.04	.28
Honest John & Launcher	26.28	28.98	13.05	39.41

[1] $A = .577\,(A_e + A_{pl} + A_{pr})$

From Whittenburg, et al., (1959a).

By measuring the area projected by a given target item on a horizontal plane (A_{pl}), on a vertical plane perpendicular to its centerline (A_{pr}) and on a vertical plane parallel to its centerline (A_{el}) a good approximation can be made to its total projected area (A) for any direction using the above formula....

... The calculation of projected area of a target previously described has only one variable in its determination, and that is the direction from which it is being viewed. Since this direction alone determines the direction cosines which give relative weight to the three projected areas, the variation in the value of the projected area could be collapsed by selecting a direction which is reasonably central among all those which may occur. By splitting the difference between the theoretical extremes of both view angle (0^o to 90^o), and target orientation to the flight path (parallel to perpendicular) we may select a direction which gives equal weight to each of the three basic projections (A_{pl}, A_{pr}, and A_{el}) of the target's area. Each of the three basic projected areas has a normal associated with it: vertical, parallel to ground track and perpendicular to ground track. For the arbitrarily selected direction to give equal weight to each of the basic projected areas, the cosines of the angles between the direction of view and the respective normals must all three be equal. (The angles themselves, then, are also equal.) Since the square root of the sum of the squares of the 3 direction cosines must equal unity,

$$\sqrt{3 \cos^2 \Theta} = 1 \qquad \text{or} \qquad \cos \Theta = 0.577$$

For any given target, then, a general approximation to its projected area is given by:

$$A = 0.577 (A_{pl} + A_{pr} + A_{el}).\text{"}$$

<u>Distinctiveness.</u> Since a reference scale for target distinctiveness is not available at the present time, the value for an expected target can only be roughly estimated. The following guidelines may be followed:

1. Assign a value from 1 to 4 if the target is expected to be camouflaged or if it will be low contrast located under trees, etc. Examples of targets from the Whittenburg study which were assigned distinctiveness values of 1 to 4 included: low contrast machine guns emplaced in partially cluttered areas near bushes and trees, a jeep located in heavy shadow under a tree, and a tank covered with a camouflage net.

2. Assign a value from 5 to 8 if the target is expected to be of medium contrast and is located in areas which have only scattered vegetation. Examples of targets in this distinctiveness range were trucks and jeeps parked near the edge of woods, and groups of machine guns and mortars emplaced in a row.

3. Assign a value from 9 to 12 if the target is expected to be high contrast located in the open. Examples of high distinctiveness targets from the Whittenburg study were high contrast machine guns and recoilless rifles emplaced in open areas, and tanks and trucks parked in the open along the side of a road.

Terrain Type. When using the Erickson (1961) graphs to obtain probability of a line-of-sight, terrain must be classified as fairly smooth, moderately rough, or rough. Table B-4 shows how Erickson defined each of the three types of terrain in terms of average slope, number of slope direction changes, and average distance to first hill per 12,000 ft. section of the terrain.

Calculation of Model Predictions

In using the model to predict the probability of detection/identification of an expected target, the same values obtained for the Whittenburg targets (Table B-1) must be calculated. The example in Table B-5 may be used as a guide.

The following is a summary of the steps in calculating predicted probabilities of detection/identification for an expected target using estimates of the input variables.

1. Obtain the threshold slant range, R_I, of the target from Figure B-3.

2. Choose values of closest slant range, R_o, for which the probability will be obtained.

3. Determine all of the slant and ground ranges D_o, D_I, M, D_M, and R_M.

4. For each slant range, R_o, calculate the square root of average square mil size.

TABLE B-4

DESCRIPTIONS OF TERRAIN TYPES [1]

	TERRAIN TYPE		
Per 12,000-foot Section	Fairly Smooth	Moderately Rough	Rough
Average slope, degrees	2	8	12
Number of slope direction changes	1	6	9
Average distance to first hill or mountain (ft.)	7500	6750	3500

[1] From Erickson (1961).

TARGET No.	TARGET Description	TARGET Area (Yds)	R_o	D_o	R_I	D_I	M	D_M	R_M	S_1	S_2	$\sqrt{S}$	C	T_o	T_s	P_o	P_M	$\bar{P}$	T_e	$\sqrt{S}\,CT_e$	P_{TDI}
12	Tank	29.81	5500	5499	6000	5999	4191	5999	6000	8.87	7.45	2.86	12	76.35	1	.44	.37	.405	.405	14	.21
			5000	4999				5999	6000	10.73	7.45	3.02		69.53	1	.53	.37	.45	.45	16	.23
			4000	3999				5727	5728	16.77	8.17	3.53		55.89	1	.68	.42	.55	.55	23	.32
			3000	2998				4311	4312	29.81	14.43	4.70		42.24	1	.81	.63	.72	.72	41	.495
			2000	1998				2897	2899	67.07	31.92	7.03		28.61	1	.88	.81	.845	.845	71	.69
			1500	1497				2189	2191	119.24	55.88	9.35		20.41	1	.92	.87	.895	.895	100	.81
			1000	995				1480	1483	268.29	121.99	13.97		14.93	1	.96	.92	.94	.94	158	.925
			800	794				1196	1200	419.13	186.31	17.40		12.19	1	.97	.94	.955	.955	199	.965
			600	592				911	916	745.25	319.75	23.08		9.44	1	.98	.95	.965	.965	267	.99
			500	490				767	773	1,073.16	449.00	27.59		8.05	1	.99	.96	.975	.975	323	.99
			400	387				622	630	1,676.81	675.96	34.30		6.64	1	.99	.97	.98	.98	403	.99
			300	283				476	486	2,981.00	1,135.89	44.82		5.22	1	.99	.98	.985	.985	530	.99
			200	173				323	338	6,707.25	2,348.38	67.29		3.72	.86	1.00	.99	.995	.86	690	.99
			150	112				240	260	11,924.00	3,968.81	89.14		2.89	.76	1.00	1.00	1.00	.76	813	.99

Terrain: Smooth

V: 100 m.p.h.

H: 100 ft.

Table B-5. Example Calculations of Probability of Detection/Identification.

5. For each slant range, calculate effective exposure time, T_e, by obtaining total possible time, converting to effective time-score, and adjusting for average probability of a line-of-sight.

6. Finally, obtain effective size exposed, $\sqrt{S}\ CT_e$, at each slant range, and read the probability of detection/identification from Figure B-7.

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